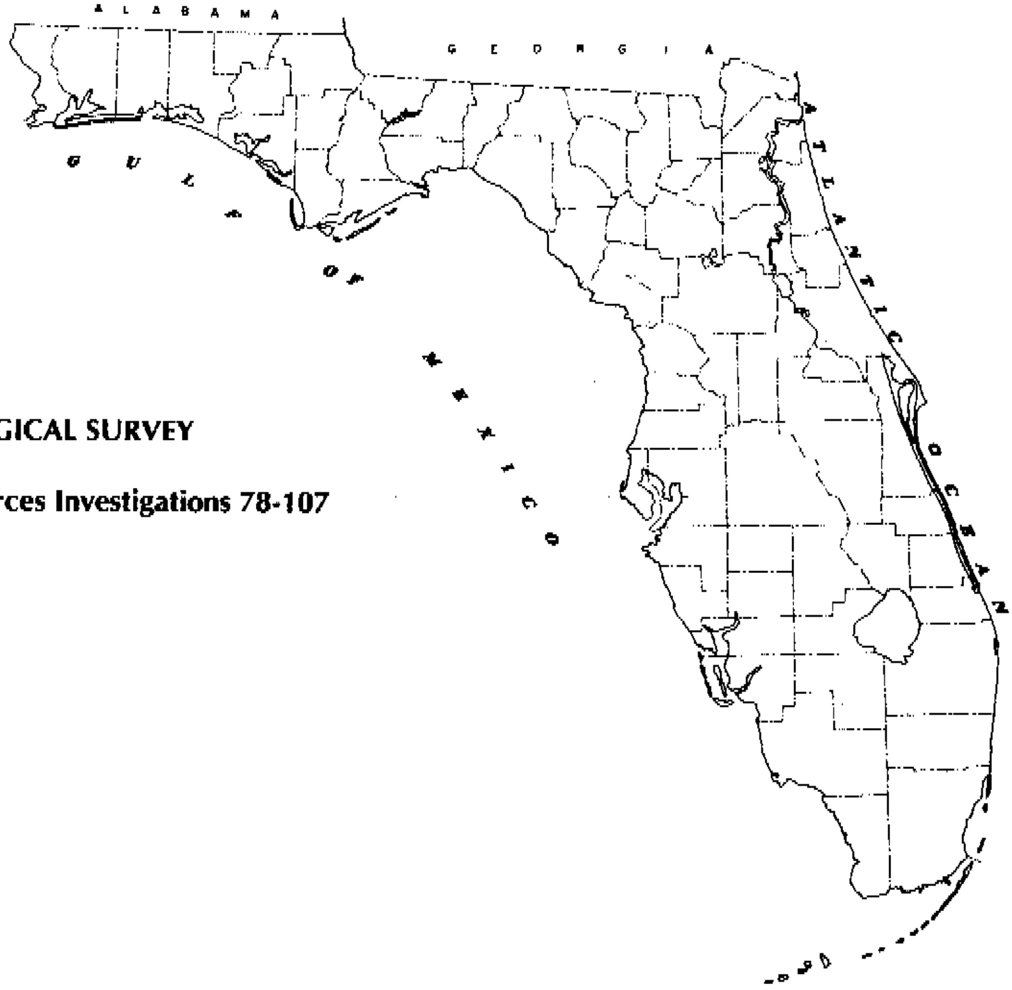
WRI 78-107

BISCAYNE AQUIFER, SOUTHEAST FLORIDA



U.S. GEOLOGICAL SURVEY

Water-Resources Investigations 78-107

Prepared in cooperation with
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WRI 78-107 BISCAYNE AQUIFER, SOUTHEAST FLORIDA

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BISCAYNE AQUIFER, SOUTHEAST FLORIDA

By

H. Klein and J. E. Hull

ABSTRACT

Peak daily pumpage from the highly permeable, unconfined Biscayne aquifer for public water-supply systems in southeast Florida in 1975 was about 500 million gallons. Another 165 million gallons was withdrawn daily for irrigation. Recharge to the aquifer is primarily by local rainfall. Discharge is by evapotranspiration, canal drainage, coastal seepage, and pumping. Pollutants can enter the aquifer by direct infiltration from land surface or controlled canals, septic-tank and other drainfields, drainage wells, and solid-waste dumps. Most of the pollutants are concentrated in the upper 20 to 30 feet of the aquifer; public supply wells generally range in depth from about 75 to 150 feet. Dilution, dispersion, and adsorption tend to reduce the concentrations. Seasonal heavy rainfall and canal discharge accelerate ground-water circulation, thereby tending to dilute and flush upper zones of the aquifer. The ultimate fate of pollutants in the aquifer is the ocean, although some may be adsorbed by the aquifer materials en route to the ocean, and some are diverted to pumping wells.

INTRODUCTION

Attention has recently been directed to the effects of rapid growth in southeast Florida on the quality of the water in the Biscayne aquifer--the prime source of drinking water in the area. Attendant with rapid growth has been such practices as: (1) Use of french drains and disposal wells for the discharge of some storm water and industrial wastes; (2) widespread and scattered emplacement of solid-waste disposal sites; (3) installation of thousands of septic tanks for individual residences, apartment dwellings and small industries; (4) discharge of various types of runoff or effluent into shallow soakage pits; and (5) discharge of treated and partly treated sewage effluent into controlled drainage canals and soakage pits. There has also been concern about the long-term use of fertilizers and pesticides in the agricultural areas of southeast Florida and in the urban areas where large quantities are used for lawns and gardens.

As early as 1971, the U.S. Environmental Protection Agency (EPA), became concerned over the quality of the surface water and ground water in Dade County and made an inventory of waste sources in the county. The EPA has been petitioned (in 1978) to designate the Biscayne aquifer as a sole-source aquifer (under Section 1424 E, Safe Drinking Water Act of 1974). The U.S. Geological Survey was requested by the EPA to furnish information on geology, hydrology, water quality and other data which would assist them in the decision regarding such designation of the Biscayne aquifer.

Since the late 1930's, the U.S. Geological Survey has been involved in investigations of the water resources of southeast Florida in cooperation with Federal, State, and many local agencies. The investigations have resulted in the collection of large amounts of basic data and in numerous reports on various aspects of the hydrology of the Biscayne aquifer. This report is based on information contained in those reports and in reports by local governmental agencies and by consultants. Basic data from files of local, State, and Federal agencies were also used. No new field data were collected for this investigation.

The following factors may be used to convert U.S. inch-pound units to SI units.

Multiply U.S. inch-pound units	By	To obtain SI units
	Length	
inch (in)	25.4	millimeters (mm)
	0.0254	meter (m)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometers (km)
	Area	
acre	4047	square meters (m^2)
square mile (mi^2)	2.590	square kilometers (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3785	cubic meters (m^3)
	Flow	
gallons per minute (gal/min)	0.06309	liters per second (L/s)
cubic feet per second (ft^3/s)	.02832	cubic meters per second (m^3/s)
million gallons per day (Mgal/d)	.04381	cubic meters per second (m^3/s)
feet per day (ft/d)	.3048	meters per day (m/d)
feet squared per day (ft^2d)	.0929	meters squared per day (m^2/d)
gallons per minute per foot (gal/min/ft)	.01923	liters per second per meter (L/s [illegible])

BISCAYNE AQUIFER

Description

The Biscayne aquifer supplies all municipal water supply systems from south Palm Beach County southward (fig. 1), including the system for the Florida Keys which is supplied chiefly by pipeline from the mainland. It is a highly permeable wedge-shaped unconfined aquifer that is more than 200 ft (feet) thick in coastal Broward County and thins to an edge 35 to 40 mi (miles) inland in the Everglades (fig. 2). The aquifer forms an important unit of the hydrologic system of southeast Florida (fig. 3), which is managed by the South Florida Water Management District (SFWMD).

The Biscayne aquifer is composed of limestone, sandstone, and sand. In south and west Dade County the aquifer is primarily limestone and sandstone, but in north Dade County, Broward County and south Palm Beach County the aquifer is primarily sand. Generally, the sand content increases to the north and east.

In Dade County (fig. 4) oolitic limestone and quartz sand form the upper part of the aquifer (Parker and others, 1955, Plate 4). The limestone is thickest along the coast, possibly as much as 40 ft., but the base is usually less than 20 ft below sea level. Inland, the oolitic limestone thins and then disappears beneath the peat soil of the Everglades. Oolitic limestone is usually cross-bedded.

Fine to medium grained sand fills solution cavities in the oolitic limestone. Parker and others (1955, p. 102) indicated that the solution cavities occupy a significant volume of the limestone, causing it to have high horizontal and vertical permeabilities. It is the high vertical permeability that permits rapid infiltration of rainfall to the water table. Where the limestone does not crop out, it is covered by quartz sand (fig. 4) which also permits rapid infiltration of rainfall.

In the east part of Dade County, extending north as far as Fort Lauderdale, the lower part of the oolitic limestone contains bryozoans (Hoffmeister, 1974, p. 39). The bryozoan section slopes upward to the west to emerge at the surface in the Everglades. Near the coast the bryozoan section is as much as 10 ft thick (Hoffmeister, 1974, p. 39); it thins to the west beyond the east boundary of Collier County. The bryozoan limestone is also riddled with cavities which contribute to its high horizontal and vertical permeability.

Below the bryozoan layer, the Biscayne aquifer is composed of hard limestone containing numerous cavities, often cavernous. Because of the extremely high permeability of this limestone, all large-capacity wells are completed in this part of the aquifer, generally 40 to 100 ft below the land surface. The cavernous section generally does not contain loose sand. The aquifer does, however, contain thin interbedded layers

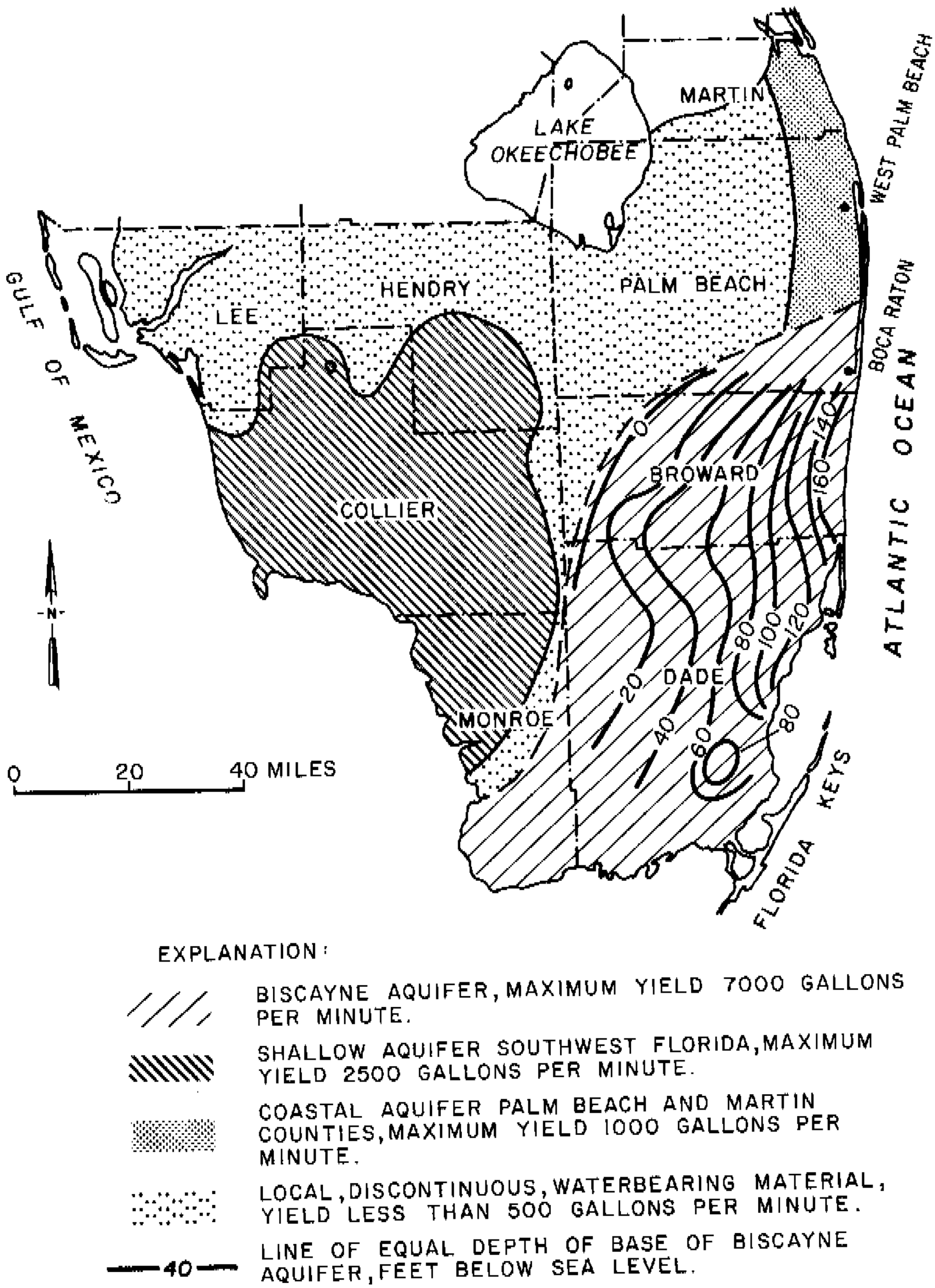


Figure 1.--Areal extent of Biscayne aquifer and adjoining shallow aquifers (Klein and others, 1975, p. 31).

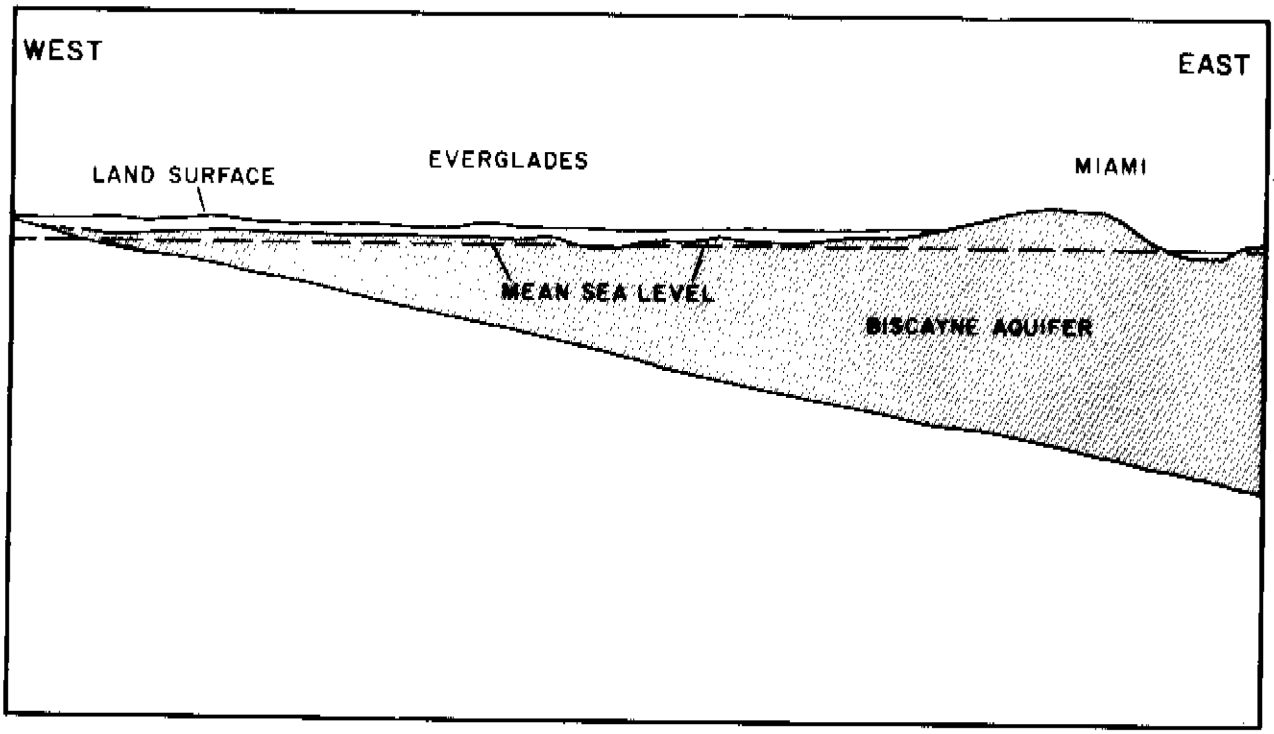


Figure 2.--Idealized section of the Biscayne aquifer (after Parker and others, 1951, figure 3).

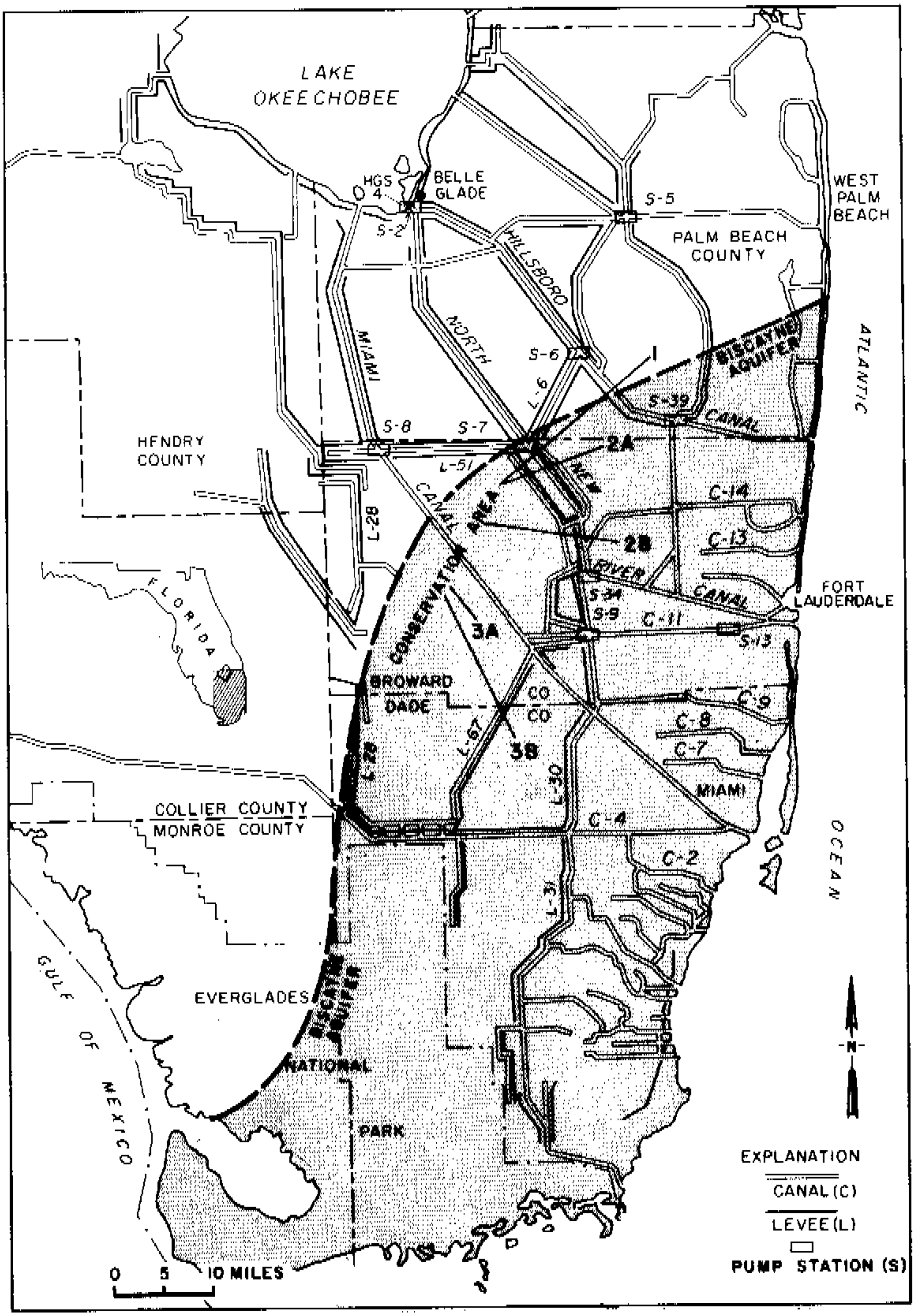


Figure 3.--Hydrologic structures and hydrologic features of the South Florida Water Management District.

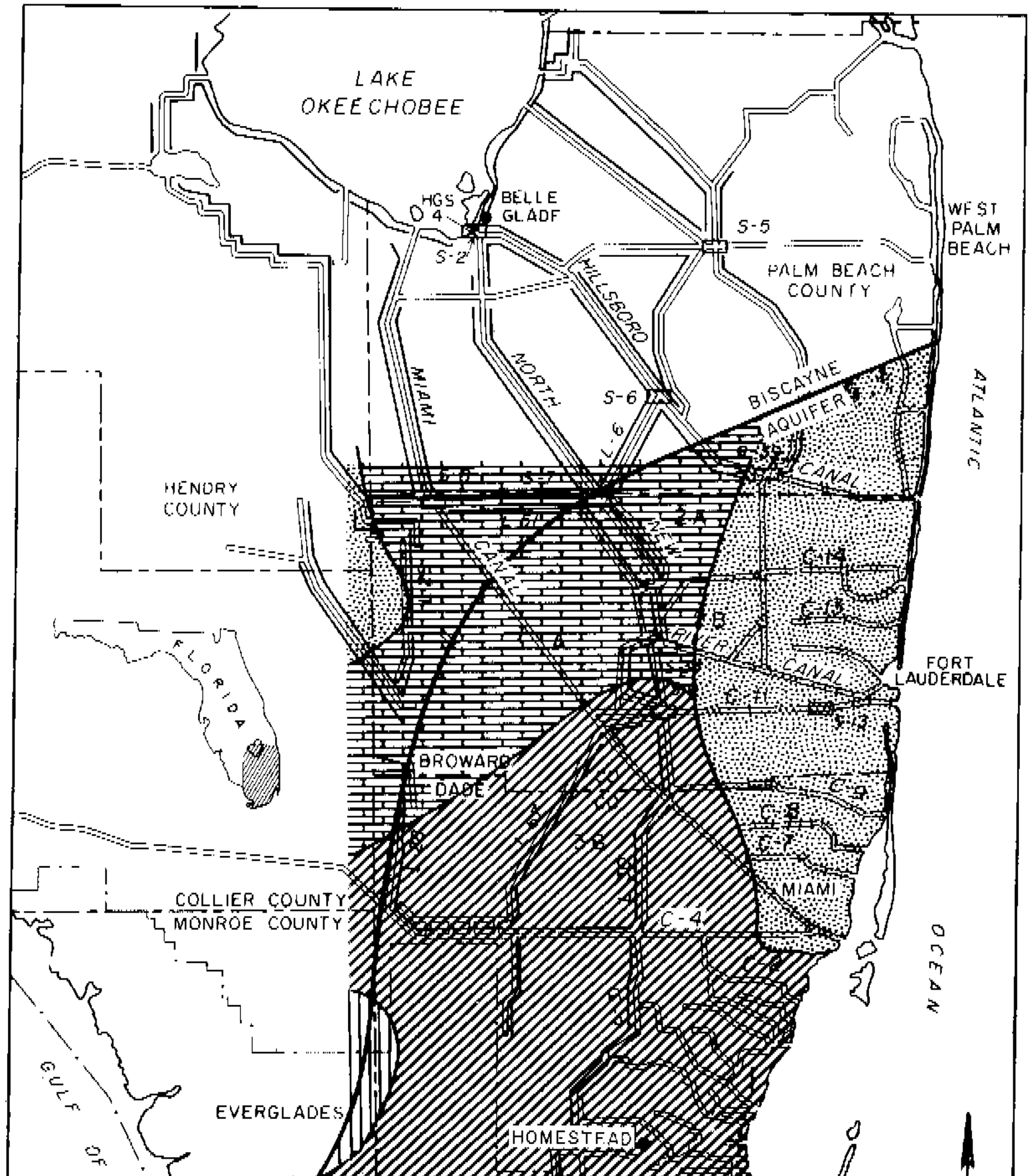


Figure 4.—Surface geology of southeast Florida (Parker and others, 1955, Plate 4).

of hard, dense limestone in south Dade County, interior parts of Dade County and southwest Broward County. The dense layers probably are discontinuous and may locally retard, but do not prevent the vertical circulation of ground water. Beneath the coastal areas unconsolidated quartz sand separates the bryozoan limestone from the deeper hard limestone. The sand content increases northward which results in a corresponding decrease in overall transmissivity of the aquifer.

Parker and others (1955, p. 160) stated that the Biscayne aquifer "is the most productive of the shallow nonartesian aquifers in the area and is one of the most permeable in the world". He suggested that in east Dade County the transmissivity (hydraulic conductivity x saturated thickness = transmissivity) of the aquifer ranges from 4 to 15 million gallons per day per foot (Mgal/d/ft) ($5.x10^5$ to $2.0x10^6$ ft^2/d). He applied a median value of 5 (Mgal/d/ft) ($6.7x10^5$ ft^2/d) (Parker and others, 1955, p. 270). These values were obtained from aquifer tests using high-capacity wells, and by analyzing water-table contours adjacent to canals and in well-field areas. Storage coefficients from aquifer tests ranged from 0.047 to 0.247 (Parker and others, 1955, table 16).

The approximate areal distribution of transmissivity of the aquifer is shown in figure 5. Along the coast and in the northern part of southeast Florida the aquifer is thickest, but because it is composed mainly of sandy material, the transmissivity is lower. In central and south Dade County the aquifer is thinner, but the hydraulic conductivity is high because of the cavernous limestone; the transmissivity is, therefore, high. The decrease in transmissivity to the west is due to the thinning of the aquifer.

The transmissivity ranges from about 3 Mgal/d per foot ($4.0x10^5$ ft^2/d) in southeast Broward County to 0.4 Mgal/d per foot ($5.4x10^4$ ft^2/d) in the northeast coastal Broward County (Sherwood and others, 1973, p 66-67) and in the vicinity of Boca Raton (McCoy and Hardee, 1970, p. 25). Values increase to about 4 Mgal/d per foot ($5.4x10^5$ ft^2/d) (Sherwood and others, 1973, p. 66) in interior parts of southern Broward County. In Boca Raton, fine and medium sand extends to at least 60 ft below the surface. Permeable limestone at greater depth is discontinuous and becomes increasingly sandy north of Boca Raton (McCoy and Hardee, 1970, p. 7-11). Storage coefficients in Broward County are as high as 0.34 (Sherwood and others, 1973, p. 67).

Soil Cover

The soil that covers southeast Florida is of hydrologic importance because it controls the infiltration of rainfall, the operation of septic tanks, and indirectly relates to the quality of the ground water. The infiltration of rainfall is rapid in areas covered by sand or where soil is absent; infiltration is retarded in areas covered by marl or clayey soil.

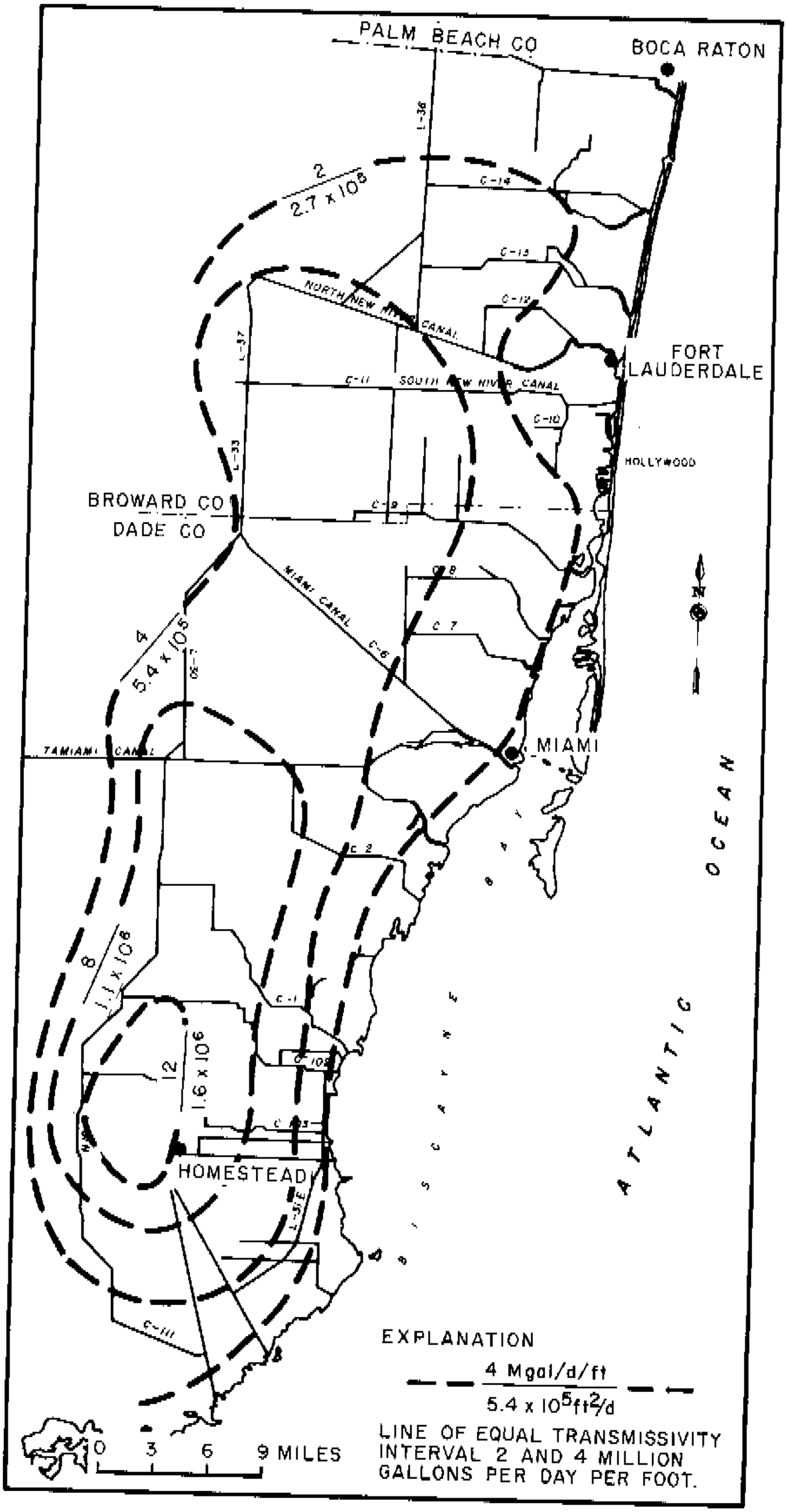


Figure 5.--Lines of equal transmissivity of the Biscayne aquifer (from Appel, 1973, figure 8).

Soil types in south Florida are shown in figure 6 (Klein and others, 1975, p. 11). Infiltration of rainfall is rapid through the sandy soil along the coast from central Dade County north into Palm Beach County. In east and south Dade County, oolitic limestone crops out or is covered by a thin veneer of sand, except in local elongate depressions where a few inches to a few feet of marl overlay the limestone. Peat and marl soils cover the Everglades. The ground water is highly colored in the area covered by or adjacent to peat soils. Septic-tank drainfields dispense effluent efficiently in sandy soil and in areas where they are cut into oolitic limestone.

HYDROLOGIC SYSTEM

The hydrologic system of southeast Florida is significantly controlled and managed by the SFWMD. The District maintains and operates a system of canals, levees, pump stations, control structures in canals, and large water-conservation areas for flood control, water conservation, and salinity control. The levees impound freshwater in Lake Okeechobee and three water conservation areas (figs. 3 and 7). The levees also prevent overland sheet flow from the Everglades eastward through the agricultural and urban coastal areas.

Canals drain the urban coastal area. They also transfer water from the water-conservation areas and Lake Okeechobee to the east coast to replenish the Biscayne aquifer in the vicinity of municipal well fields and to retard saltwater intrusion. Canal flows are regulated by control structures near the coast which open and close repeatedly during the rainy season and occasionally during the dry season. Flow in the canals is regulated so ground-water levels in the urban areas and bordering farm lands are maintained at levels low enough to prevent flooding. The volume of outflow to the ocean varies, depending upon rainfall. At the end of the rainy season most control structures are closed to conserve freshwater and prevent saltwater from moving inland; thereafter levels decline to annual low levels usually in May.

Water releases from Conservation Area 3 (fig. 3) are made to the south during the year to sustain plants and animals in the Everglades National Park. During much of the dry season, water levels near the coast are maintained by direct seepage from the water-conservation areas. During prolonged drought, the canals transfer water from Lake Okeechobee through the conservation areas to points of need along the coast. Lake water is shared by local municipalities, Everglades National Park, and agricultural interests.

The hydrology of southeast Florida was affected significantly before 1945 when the prime objectives were land drainage and reclamation. Water levels were lowered an estimated 5-6 ft in parts of southeast Florida as a result of the virtual uncontrolled drainage (Leach and others, 1972, p. 96). An adverse effect was saltwater intrusion into some municipal wells of the water-supply system of Miami.

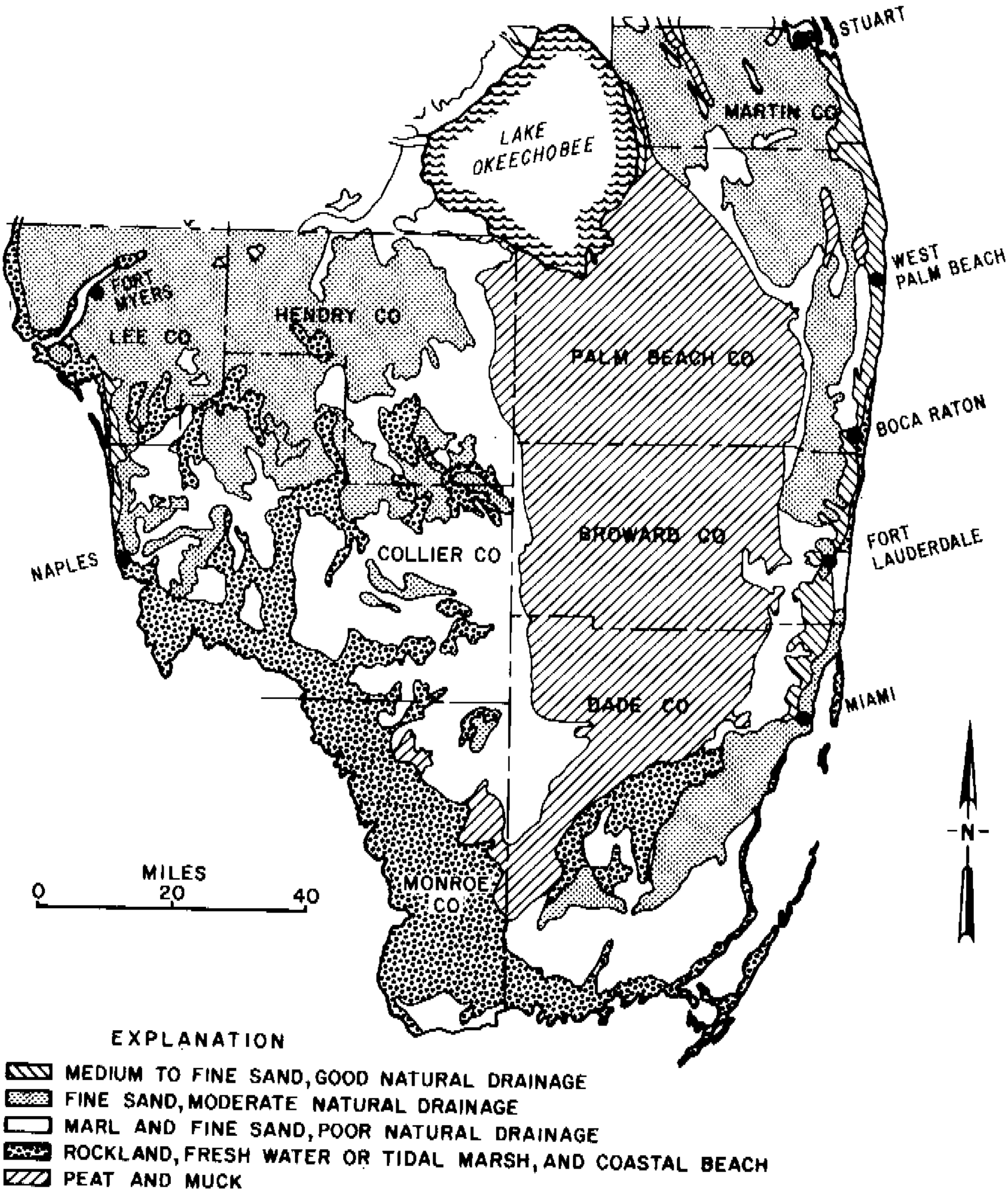


Figure 6.—Distribution of soil types (after General Soil Map, Soil Conservation Service, 1962).

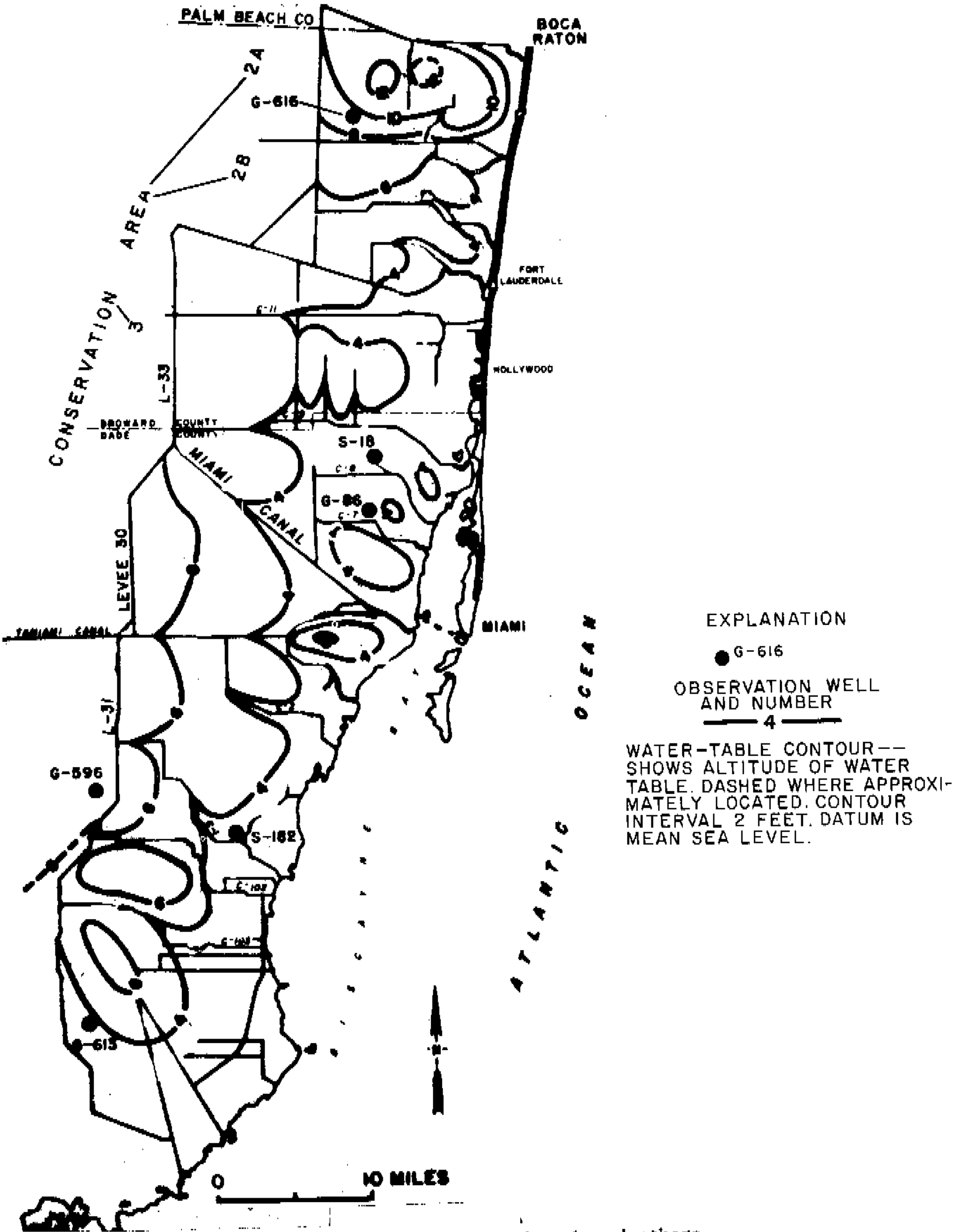


Figure 7.--High ground-water levels, June 1968 (Leach and others, 1972, figure 32).

The period after 1946 was one of flood protection, water control and conservation, and water management. Control structures were placed in all major drainage canals and water-conservation areas were established in the interior. The control structures were opened to discharge flood water during rainy seasons, and were closed to prevent overdrainage of ground water, thereby slowing or halting saltwater intrusion. Water stored in the conservation areas helped to sustain high water levels near the coast.

Saltwater intrusion is an ever-present threat. The water-control and management practices have stabilized the inland movement of saltwater into the aquifer in most areas. Some inland migration still occurs, primarily in south Dade County.

The major problems facing water-management agencies are: (1) Satisfying the water demands of an increasing population while making sufficient water available for irrigation and maintaining aquatic environments; and (2) Upgrading and maintaining water quality in the Biscayne aquifer, the water conservation areas, and in the canals and lakes.

Ground Water

The regional flow of ground water in southeast Florida is seaward. Locally, however, the direction of flow may be influenced by drainage canals or well fields. Water levels are highest in the water-conservation areas and lowest along the coast, along uncontrolled reaches of canals, and in the centers of large municipal well fields. During rainy seasons control structures in canals are opened in order to discharge surplus water to prevent flooding in urban and agricultural areas. Opening the controls lowers the level in the canals, thereby, permitting more ground water to move to the canals and then seaward. Rainy season high-water levels of June 1968, one of the highest of record in southeast Florida, are shown in figure 7.

At the beginning of the dry season control structures are closed and normally remain closed until the next rainy season. Figure 8 shows water levels near the end of the dry season of 1961-62, a near record low in southeast Florida. At that time the canals were picking up ground water in inland areas and transporting it to the coastal areas where canal levels were being maintained to help retard saltwater intrusion by infiltration from canals.

All the fresh ground water used in Dade and Broward Counties is from the Biscayne aquifer. Large capacity municipal wells commonly contain 40 to 60 ft of large diameter casing, 6 to 42 in, and open hole below the casing to 75 or 100 ft in Dade County, and deeper in Broward County. Yields are from 500 to more than 7,000 gal/min (gallons per minute); water-level drawdowns are small. Specific capacities from tests of several days' duration are from about 1,000 gal/min/ft of drawdown in Dade County to 200 gal/min/ft in north Broward and southeast Palm Beach Counties.

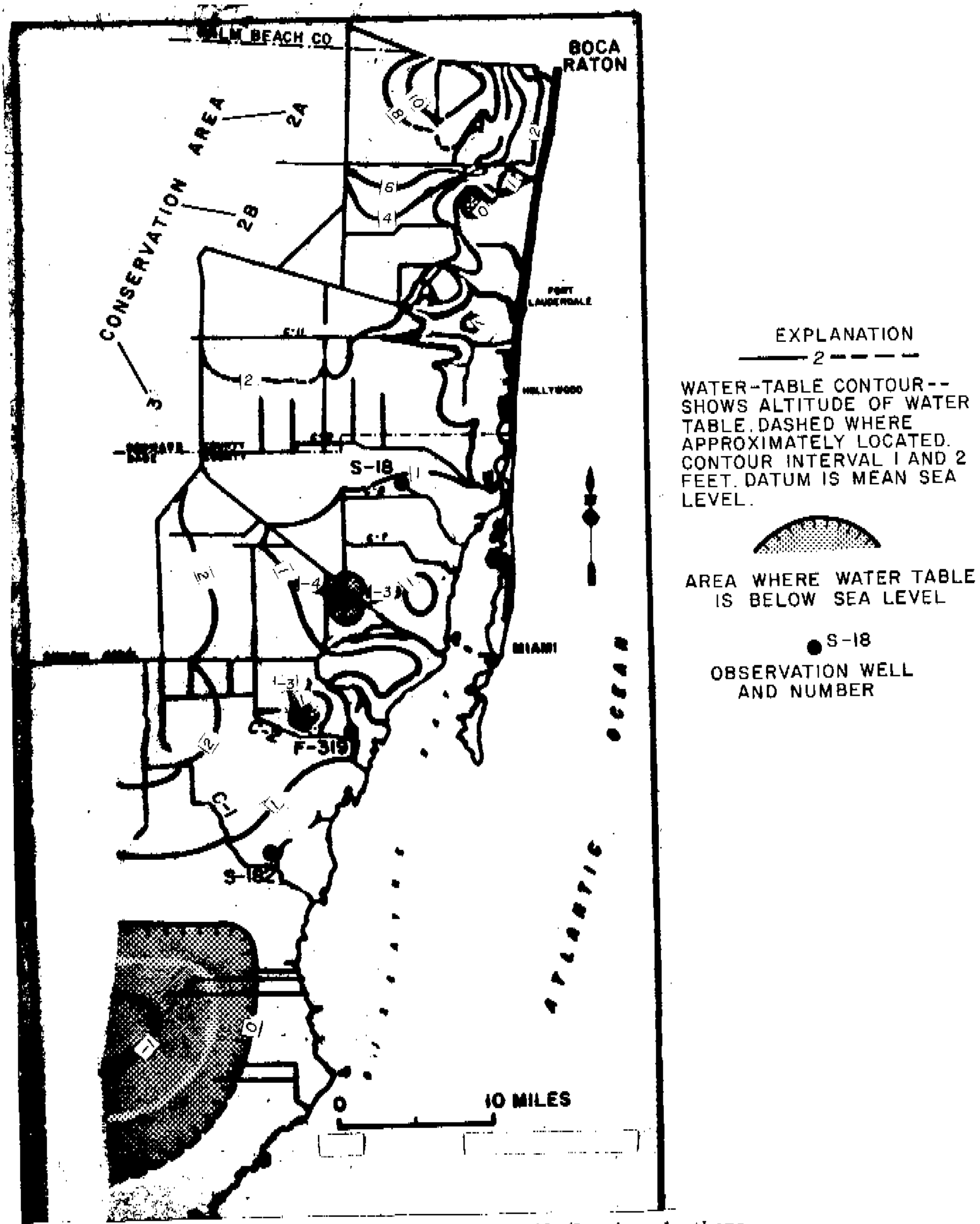


Figure 8.—Low ground-water levels, May 1962 (Leach and others, 1972, figure 30).

In the agricultural areas of south and interior Dade County, irrigation wells are usually rotary drilled to depths of 25 to 35 ft. Casing is not required because the aquifer is solely limestone. Hundreds of these wells are drilled at spacings as small as 300 ft. A large capacity irrigation pump mounted on a truck is moved from well to well and each is pumped for short intervals at rates of 500 to 1,000 gpm.

Thousands of small diameter (2-inch) wells are used throughout the year for irrigation of residential lawns and shrubs. These wells, about 20 to 50 ft deep, are normally pumped at rates of 25 to 40 gpm. In areas near the coast or adjacent to tidal canals no fresh ground water is available so residences use municipal water for lawn irrigation. Shallow wells of small diameter are also used for domestic supplies in areas not serviced by municipal systems.

Recharge and Discharge

The Biscayne aquifer is recharged principally by rainfall. The average annual rainfall in the lower east coast area varies areally from 58 to 64 in; the annual extremes experienced are 29 in and 106 in (Leach and others, 1972, p. 9-10). The rainy season, June - October, contributes about 70 percent of the total. During this period heavy rains are associated with tropical disturbances and frequent short, local downpours. Light to moderate rainfall during the dry season is associated with cold fronts moving southward through Florida.

The oolitic limestone and sand that form the upper surface of the aquifer readily absorb rainfall and move it rapidly to the water table. The rapid response of the water table to rainfall in the Miami area is indicated in figure 9. Infiltration of rainfall is retarded but not prevented in interior parts of Dade and Broward Counties where thin marl deposits cover the surface, and along the shallow elongate depressions that dissect the urban area. Other sources of recharge to the aquifer are: (1) Connate ground water of inferior quality (Parker and others, 1955, fig. 221) along the upper reaches of the Miami, the North New River, and the Hillsboro Canals in Broward and Palm Beach Counties (northwest of the limits of the Biscayne aquifer) that is transferred eastward during dry seasons; (2) Water from Lake Okeechobee released by the SFWMD into the Miami Canal during the later weeks of the dry seasons to replenish the Miami area; and (3) Effluent from septic tanks, certain sewage treatment plant and disposal ponds scattered throughout the urban area.

Parker and others (1955) and Meyer (1971) estimated that 20 in of the approximately 60 in of annual rainfall in Dade County is lost directly by evaporation, about 20 in is lost by evapotranspiration after infiltration, 16 to 18 in is discharged by canals and by coastal seepage, and the remainder is utilized by man. Sherwood and others (1973, p. 49) indicated comparable values for Broward County. Thus, nearly 50 percent of the rainfall that infiltrates the Biscayne aquifer is discharged to the ocean, a reflection of the high degree of connection between the aquifer and the canal system.

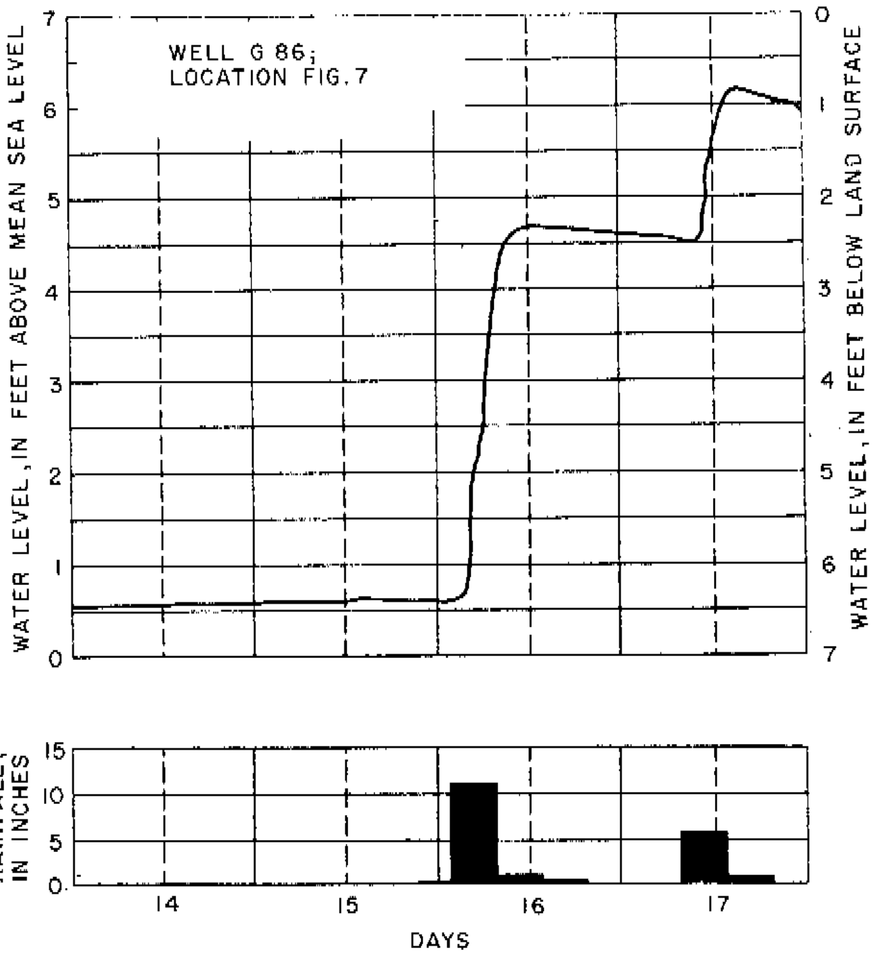


Figure 9.—Response of water levels in well G-86 to heavy rainfall, April 1942 (Parker and others, 1955, p. 216).

Figure 10 (see fig. 8 for well locations) shows long-term water-level fluctuations in observation wells in the east edge of the Everglades in Dade County (Well G-596), in south Dade County (G-613), in north Dade County (S-18), and in inland Broward County (G-616). The decline of the minimum and average water levels and the increase in the magnitude of fluctuation in wells G-596 and G-613 are the result of improved drainage in south Dade County by the digging of Canals 1, 102 and 103 (fig. 7) after 1960. The response to drainage was similar in the vicinity of well G-616 in north-central Broward County. In contrast, minimum and average levels have increased in well S-18 in north Dade County, and the range in fluctuation has decreased.

Canal-Aquifer Relation

One of the most important factors in flood control and water management in southeast Florida is the hydraulic connection between the Biscayne aquifer and the canals that dissect the aquifer (fig. 11). This inter-connection brings about benefits and problems. The benefits are: (1) Flood prevention by the rapid removal of excess water to the ocean through operation of control structures in canals; and (2) the movement of ground water from the interior to the coastal areas where it can infiltrate the aquifer and maintain high water levels to retard saltwater intrusion. Problems related to good aquifer-canal inter-connection are: (1) The movement of saltwater into the aquifer along the coast and tidal canals during times of low water; and (2) the threat of pollutants entering the aquifer from the land surface or from canals, and moving long distances. The degree of connection can be affected by the amount of sediment that accumulates along the bottom of the canals. Thus, the rate at which a canal can recharge or discharge water to or from an aquifer may change over the years because of the accumulation or removal of channel-bottom sediments.

Data relating the response of the ground-water levels to changes in canal levels (Pitt, 1976, p. 5) indicate the connection between the aquifer and the canals ranges from excellent in the permeable limestone areas of south Dade County, to poor in north parts of Broward County where the permeability of the sand is comparatively low. The influence that canals have on fluctuations of ground-water levels after rain storms in south Dade County is shown by the short-period hydrographs in figure 12 (Klein and others, 1975, p. 65); the rate of recession of ground-water levels after storms was increased markedly after canals were constructed.

The effectiveness of the canal system in removing ground water to prevent flooding in south Dade County is shown by comparing figures 7 and 13. Figure 13 shows the record high levels in south Dade County as a result of extremely heavy rainfall associated with two tropical disturbances in September 1960. Peak water levels exceeded 10.5 ft above sea level and much of south Dade County was flooded. In contrast, figure 7 shows ground-water levels after the comparable heavy rainfall in May - June 1968 when the canal-drainage system in south Dade County

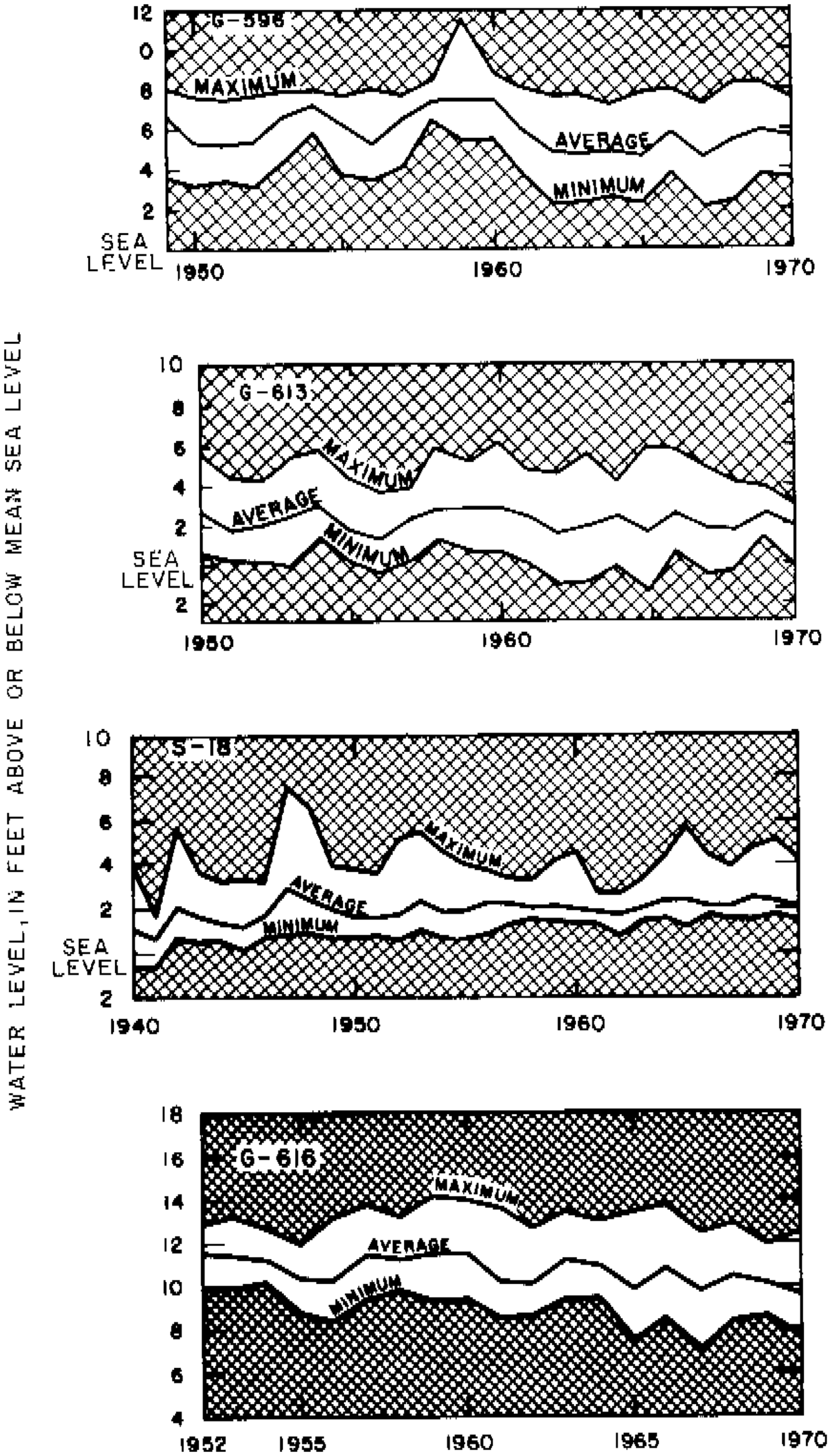
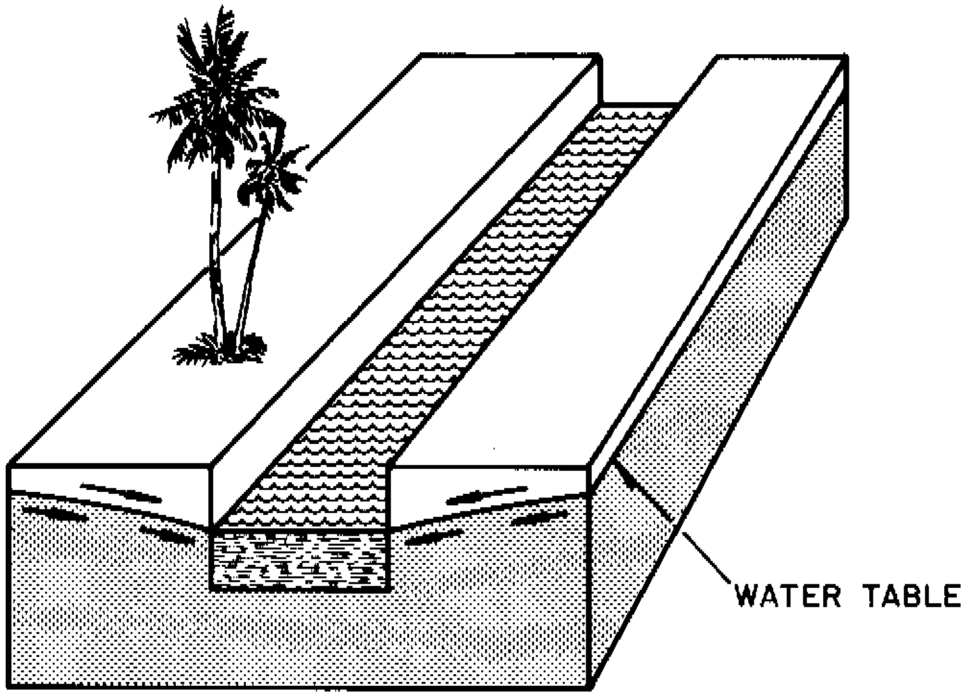
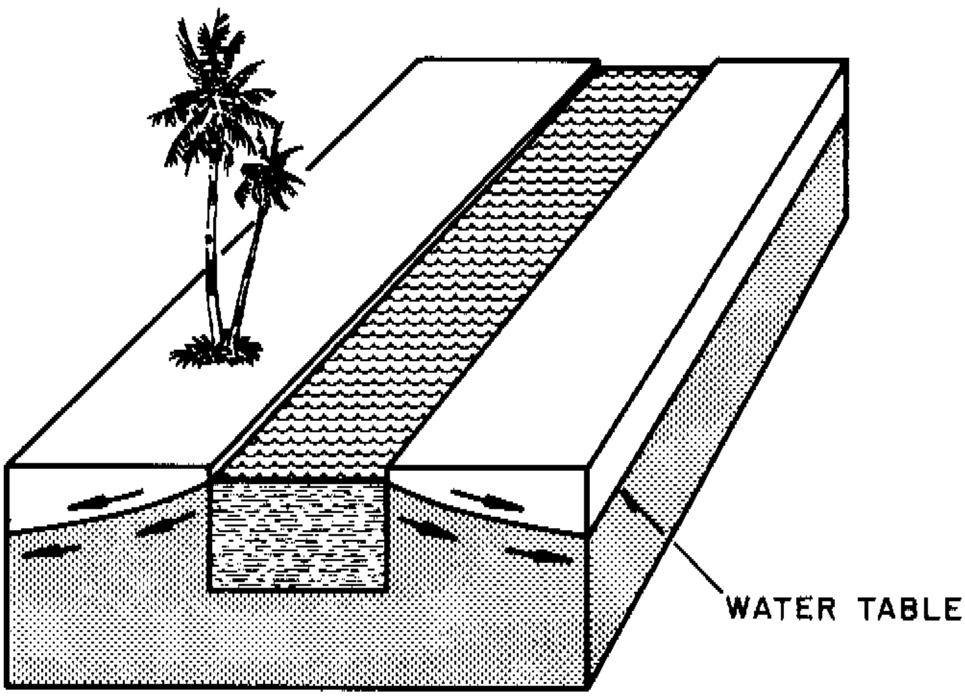


Figure 10.--Long-term hydrographs of selected wells, 1940-70 (Klein and others, 1975, p. 65-69); locations figure 7.



When the water level in an aquifer is higher than that in a canal that penetrates it, water moves toward the canal.



When the water level in a canal is higher than that in the aquifer it penetrates, water moves into the aquifer.

Figure 11.--Hydraulic connection between a canal and an aquifer (Klein and others, 1975, p. 38).

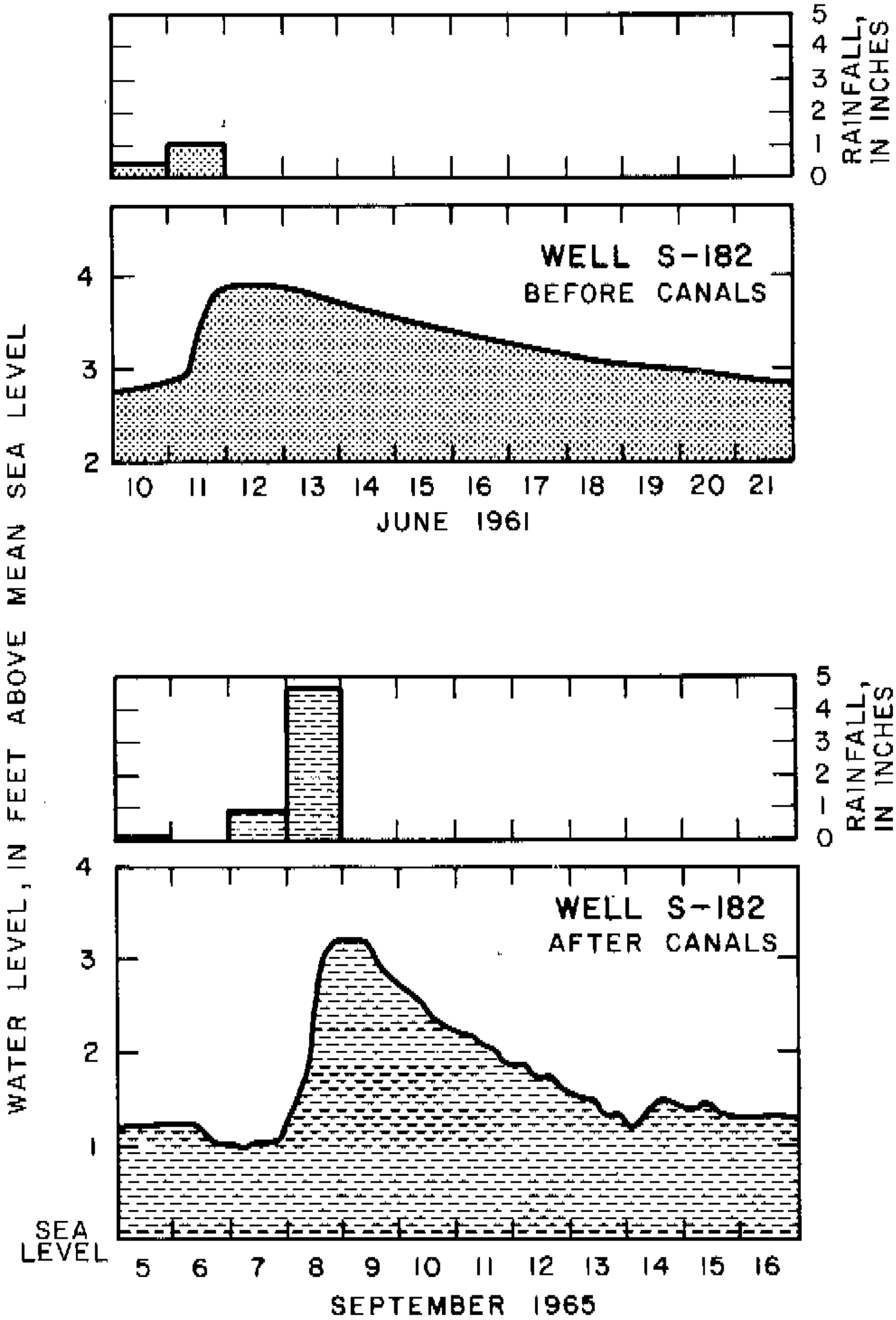


Figure 12.--Response of ground-water levels in well S-182 to rainfall and canal drainage (after Klein and others, 1975, p. 65).

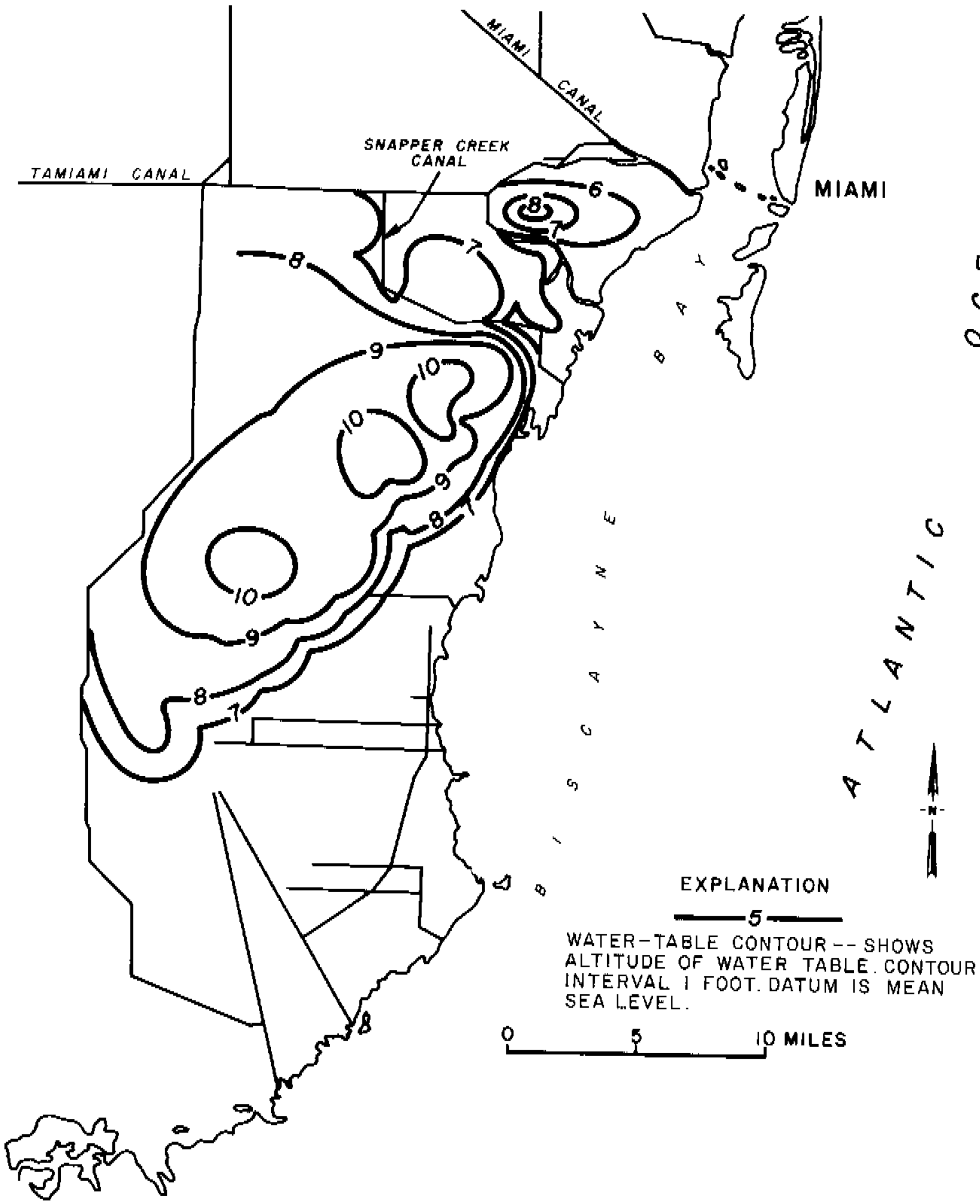


Figure 13.--Record high water levels in south Dade County, September 1960 (Klein and others, 1975, p. 63).

was operational. Drainage by the canals prevented the formation of the high, elongate ground-water mound shown in figure 13; rather, isolated mounds of lower elevation were formed in the intercanal areas.

The degree of effectiveness of the hydraulic connection is also indicated by the rate at which canal water can infiltrate downward and laterally into the aquifer during dry seasons when water levels in canals are higher than adjacent ground-water levels in the coastal area. Principal areas of concern are the canal reaches in the vicinity of the major municipal well fields. The canal-bottom sediments tend to retard but do not prevent the infiltration of canal water into the aquifer in these areas. Investigations by Meyer (1972) in the Miami Springs-Hialeah well-field area adjacent to the Miami Canal, showed that infiltration from the Miami Canal comprised 52 percent of the total water pumped in 1970 and 55 percent in 1971. Infiltration is also retarded by beds of fine sand below the oolitic limestone.

The response of ground-water levels to control-structure operations is shown in figures 14 and 15. The water-table contour pattern for July 21, 1959 shows that when the control was open ground water was moving toward all reaches of Canal C-2 and then to Biscayne Bay. The pattern for May 24, 1962 shows that when the control structure had been closed for several months, the water level in the canal was higher than adjacent ground-water levels and water was infiltrating the aquifer along all reaches, particularly to the north, toward the Alexander Orr well field. The hydrographs of C-2 Canal and wells within the basin (fig. 15) show the rapid response of ground-water levels to changes in canal levels, further evidence of the good connection between the aquifer and the canal.

Saltwater Intrusion

Saltwater intrusion affects the entire coastal zone of the Biscayne aquifer. Saltwater extends inland from the coast and along tidal streams and canals. It moves inland and upward in response to low ground-water levels, and seaward and downward in response to high ground-water levels.

The sequential maps in figure 16 show that most of the saltwater intrusion in the Miami area took place before 1946 when canal flow was virtually uncontrolled and ground-water levels were greatly lowered. Intrusion was halted during subsequent years as a result of installation of control structures in canals by the local and State water-control and water-management agencies. A readvance of saltwater occurred during the prolonged dry season of 1970-71 in the Miami and south Dade County areas as shown in figure 17.

The inland advance of saltwater in the Miami area was due to the fact that control structures in the Miami, Tamiami, and Coral Gables Canals were placed too far upstream for the effective control of saltwater movement (Parker and others, 1955, p. 705). The advance in the

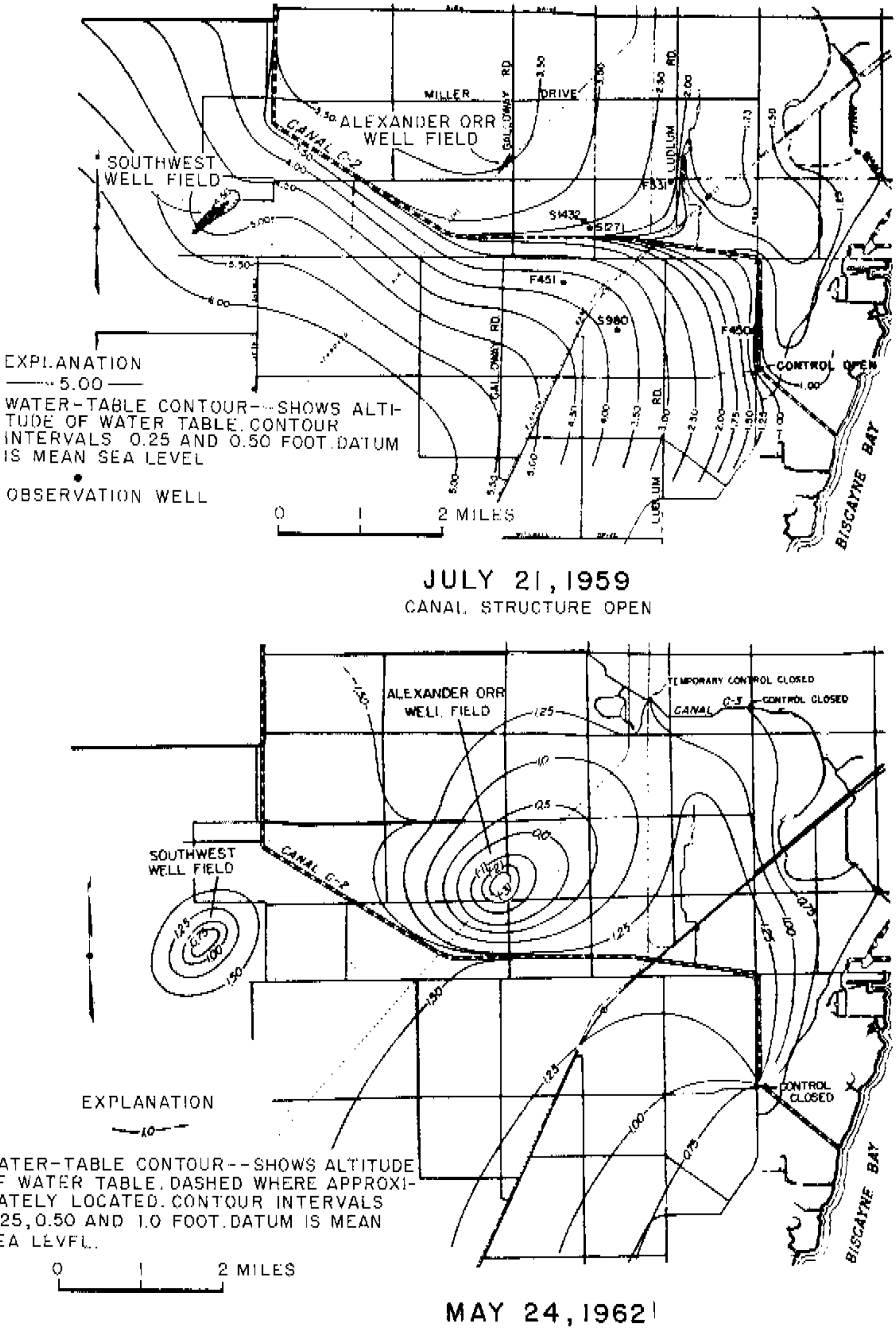


Figure 14.--Water levels in Canal 2 area, July 21, 1959 (Sherwood and Leach, 1962) and May 24, 1962 (Sherwood and Klein, 1963).

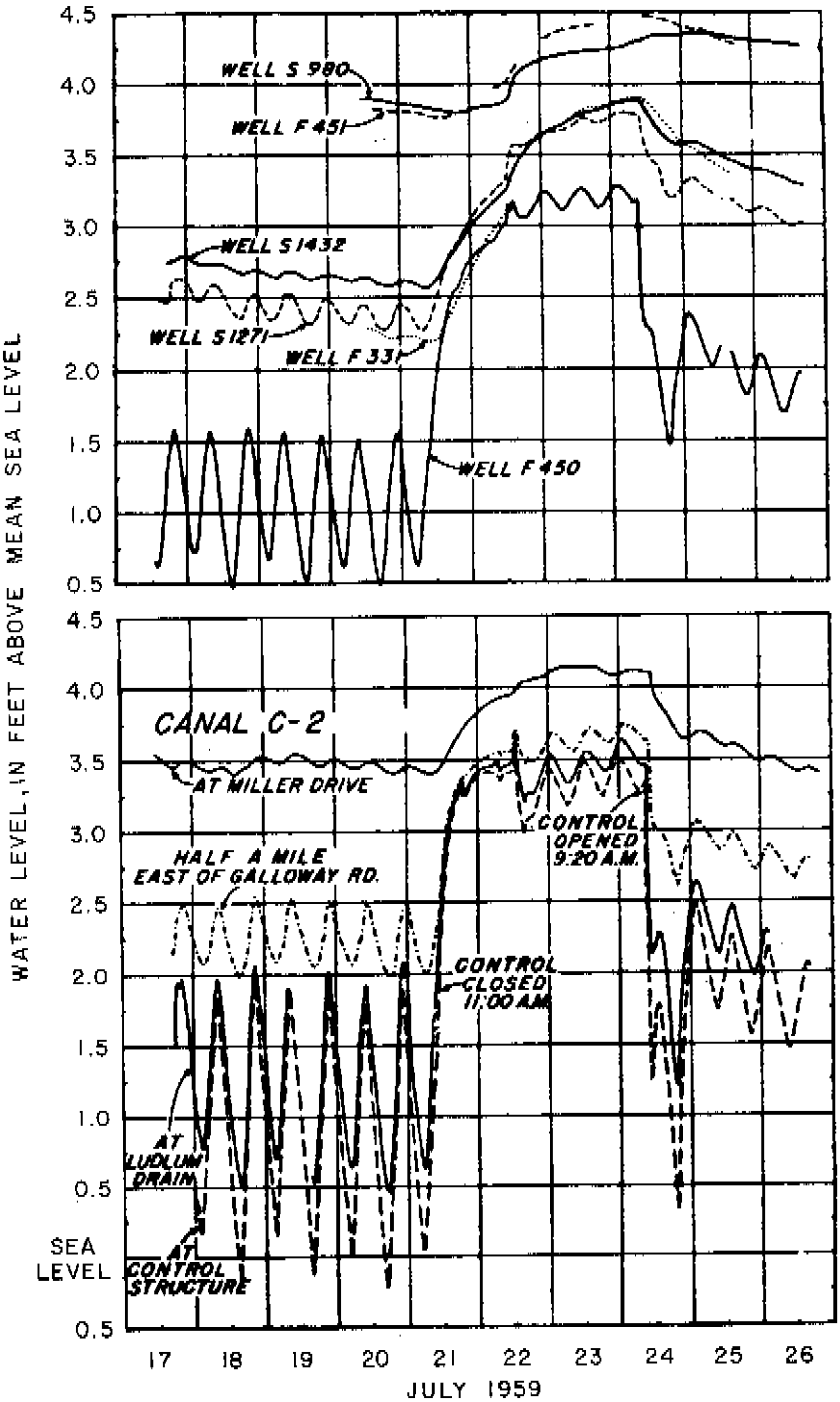


Figure 15.--Response of ground-water levels to changes in water levels in Canal 2, July 17-26, 1959 (Sherwood and Leach, 1962, p. 15); well locations in figure 14.

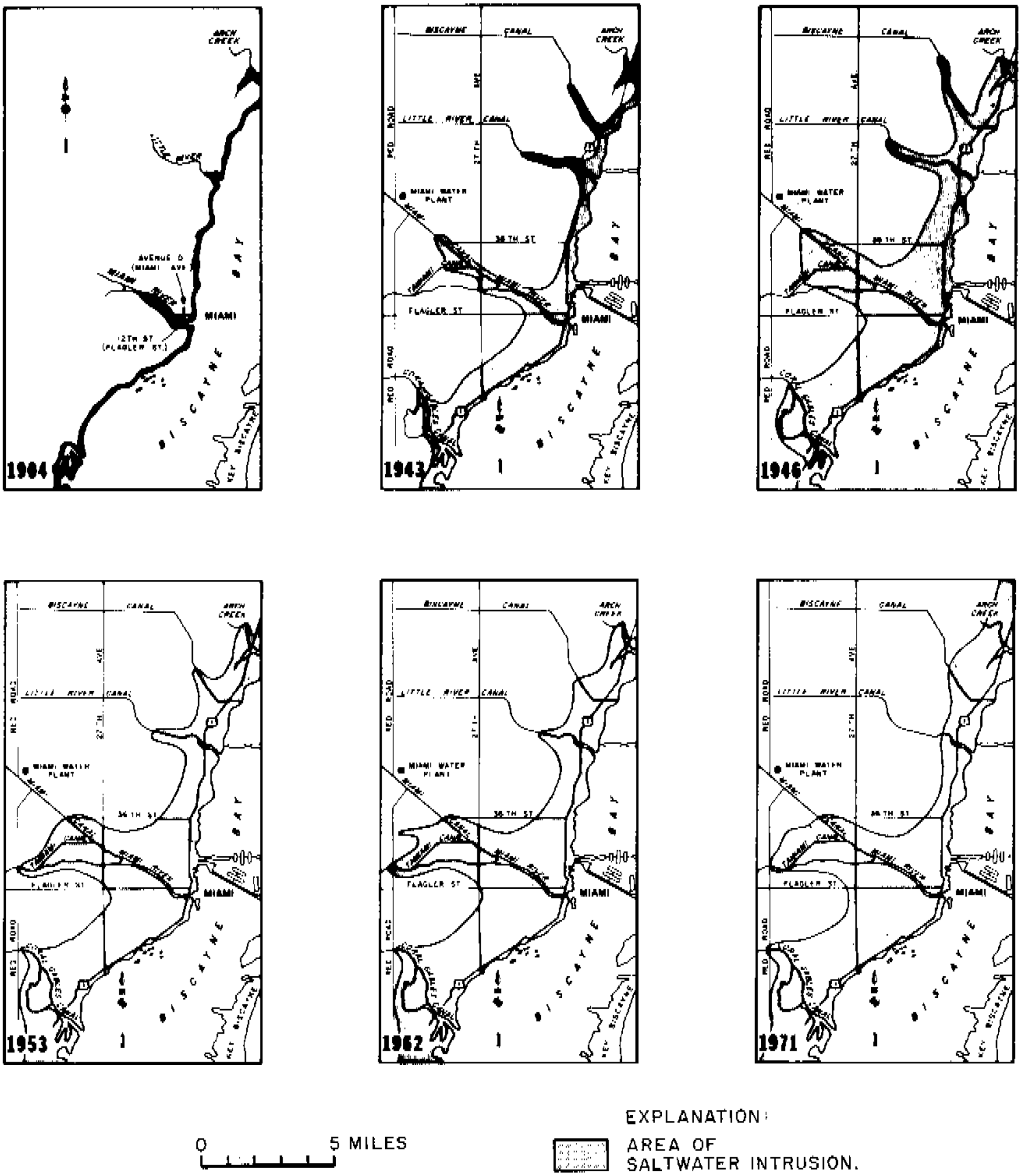


Figure 16.--Areas affected by saltwater intrusion 1904-1971 (Parker and and others, 1955, Fig. 169).

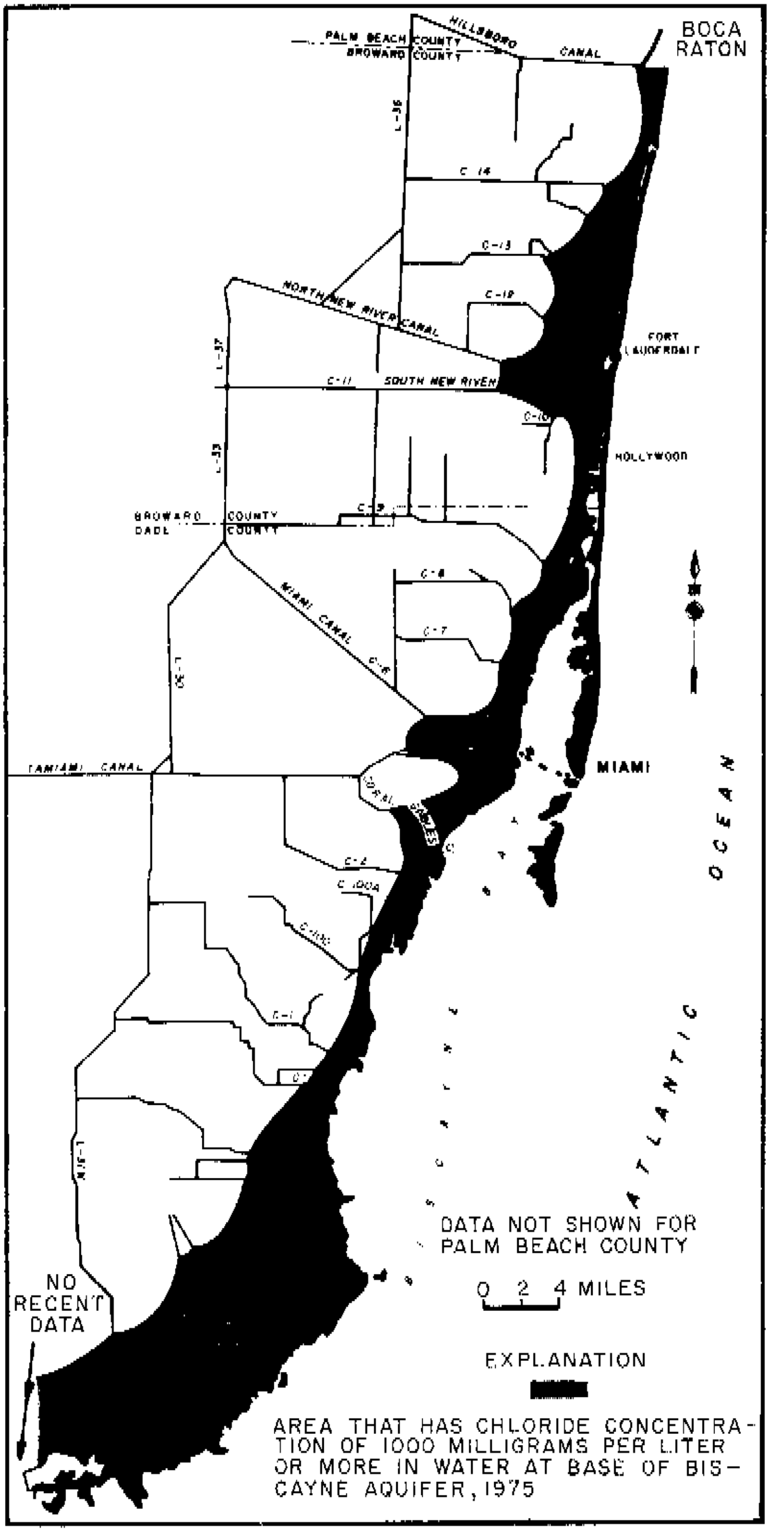


Figure 17.--Southeast Florida showing inland extent of saltwater intrusion, 1975.

Fort Lauderdale area, similarly, was the result of placement of structures too far inland in the North New River and South New River Canals. The particularly wide zone of salty ground water in southeast Dade County was the result of the maze of canals and mosquito-control ditches which lowered water levels and permitted saltwater intrusion (Parker and others, 1955, p. 711).

WATER QUALITY

The chemical quality of the ground water in the Biscayne aquifer differs slightly from place to place; most differences in quality are related to the nature of the aquifer and local land use (Pitt and others, 1975, p. 44). In general, the water is hard, a calcium bicarbonate type, and contains different amounts of dissolved iron. Dissolved constituents in the ground water are influenced by rainfall and dry fallout, reaction with soil and aquifer material, application of fertilizers and pesticides, biological processes at the surface and within the aquifer, infiltration of wastes, chemical reactions among constituents, temperature, and pressure.

Ground-water quality in the vicinity of canals is also affected by canal water during dry seasons. The areas of this type of effect probably are small because of the seasonal reversals of hydraulic gradients between the canals and the aquifer. However, where large municipal well fields near canals are pumping continuously, such as the Miami-Springs Hialeah field adjacent to the Miami Canal, the induced infiltration of canal water to the aquifer is virtually constant and a wide zone of ground water is affected by canal water.

Chemical analyses of untreated water from selected large municipal well fields that withdraw water from the Biscayne aquifer (fig. 18), are shown in table 1. Samples were collected June 1975. Also shown are analyses of water from two test wells in interior parts of Dade County (fig. 18); both wells are remote from urban and agricultural development. The test-well samples were collected in October 1973 and October 1974. The analyses from the municipal wells represent ground-water quality affected by several years of pumping, urban runoff, periodic rainfall, canal drainage and canal-water seepage, septic-tank operation, and agricultural activities. The analyses from the two interior wells can be considered base-line water quality, not affected by development. In general the analyses are similar, except for low concentrations of sulfate and potassium in the remote test wells which are distant from urban and agricultural areas where fertilizers are used regularly. For comparison table 2 shows analyses of untreated water from four public supply well fields for 1941-42--during the early stages of urban growth (Parker and others, 1955, table 114).

One of the prime problems of water treatment for municipal supplies is the high organic content of the raw ground water. Color of the water in southeast Florida is related to the proximity of the thick organic peat soils of the Everglades. As indicated in table 1, color is high in

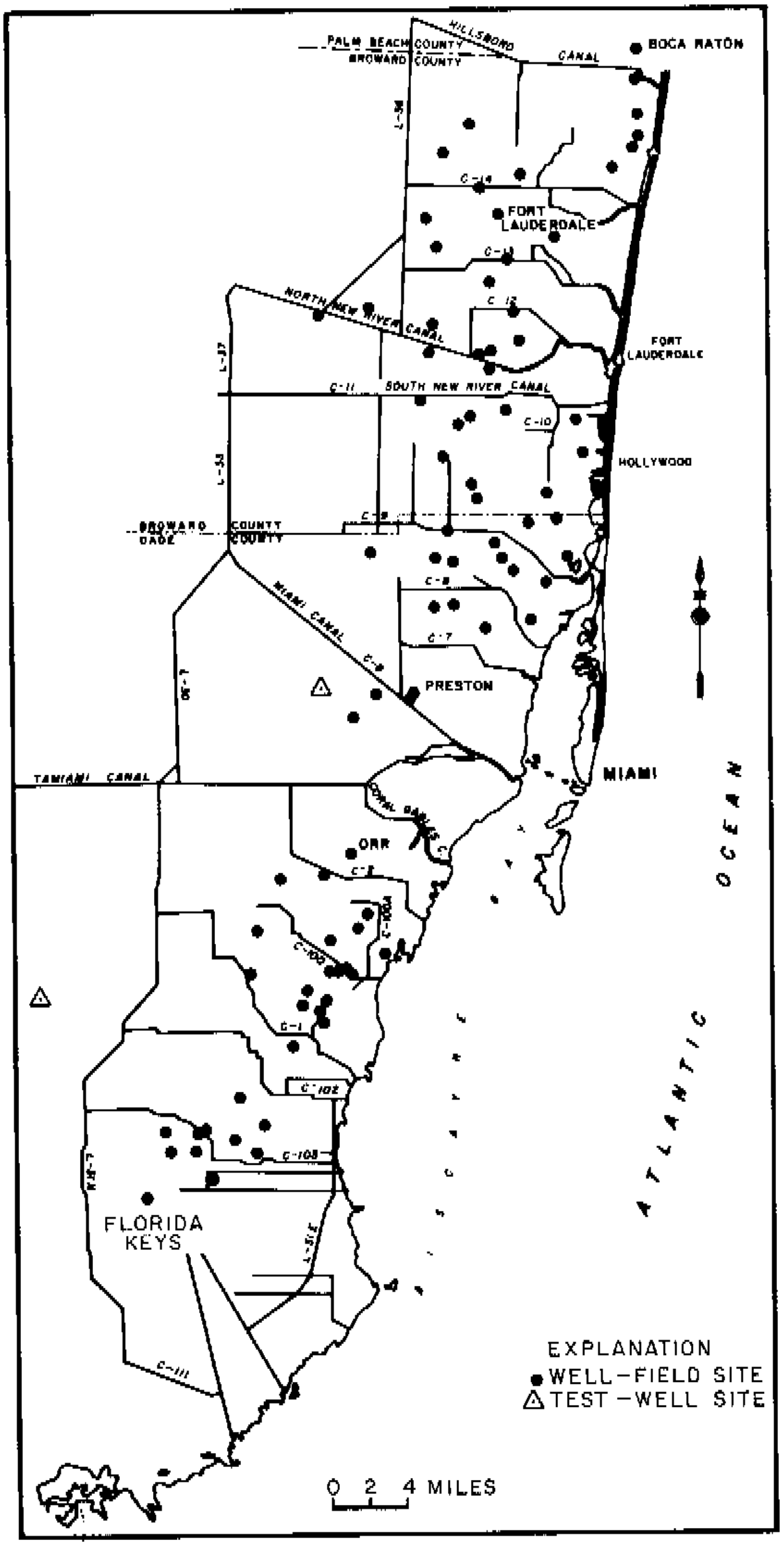


Figure 18.--Location of major public supply well fields (Broward County Land Use Plan, 1977, p. 107; Metropolitan Dade County Environmental Resources Management facilities map, 1977).

Table 1.— Analyses of untreated water from selected municipal well fields and from Everglades sites, 1973-75.

[Healy, 1977 and Pitt and others, 1975]

Constituent (Concentrations in milligrams per liter, except as indicated)	Boca Raton well field	Fort Lauderdale Fiveash well field	Miami Preston well field	Miami Orr well field	Keys Aqueduct well field, south Dade County	Northwest Dade test well	Southwest Dade test well
Silica (SiO_2)	7.5	9.7	7.0	4.3	3.2	7.1	5.3
Calcium (Ca)	80	100	90	92	100	98	81
Magnesium (Mg)	2.1	2.8	5.4	3.2	3.8	7.0	4.1
Sodium (Na)	18	19	38	16	13	17	14
Potassium (K)	1.4	1.5	3.0	1.7	5.7	0.7	0.3
Strontium (Sr)	0.75	.78	.87	.74	1.10	.89	.61
Bicarbonate (HCO_3)	212	299	272	259	236	321	263
Sulfate (SO_4)	26	26	28	28	62	1.3	0.9
Chloride (Cl)	34	33	57	25	23	29	25
Fluoride (F)	0.3	0.3	0.3	0.2	0.3	0.3	0.2
Nitrate (NO_3-N)	.01	.01	.01	.25	.00	.00	.00
Nitrite (NO_2-N)	.00	.00	.00	.00	.00	.00	.00
Nitrogen, organic (N)	-	-	1.1	-	-	.55	.89
Nitrogen (Ammonia total NH_4-N)	0.31	.63	1.10	.01	.01	1.20	.46
Iron (Fe)	.08	1.8	.90	.03	.29	2.9	-
Phosphorus, total (P)	-	-	-	-	-	.02	.00
Dissolved solids (residue at 180°C)	320	388	394	322	356	353	285
Total hardness (as $CaCO_3$)	210	260	250	240	270	280	220
Noncarbonate hardness (as $CaCO_3$)	36	15	27	28	76	13	9
Alkalinity (as $CaCO_3$)	174	245	223	212	194	263	215
pH (units)	7.0	7.4	7.6	7.5	7.5	7.3	7.8
Specific conductance (umhos/cm at 25°C)	500	619	663	540	569	567	465
Color (Pt-Co units)	7.5	45	55	5	5	-	-
Temperature (°C)	28	-	28	28	-	24.3	24
Turbidity (JTU)	-	-	1	-	-	9	16
Carbon, organic, total (C)	-	-	-	-	-	15	9.0
Orthophosphate total (PO_4-P)	-	-	-	-	-	.06	.00

Table 2.-- Analyses of untreated water from certain public supplies in southeast Florida, 1941-42.

[Data from Parker and others, 1955, table 114]

Constituent (Concentrations in milligrams per liter, except as indicated)	Boca Raton	Fort Lauderdale	Miami (Hialeah - Miami Springs)	Homestead
Color (units)	10	110	85	5
pH (units)	7.2	7.3	6.8	--
Specific conductance (K x10^5)	32.1	45.8	57.7	37.9
silica (SiO_2)	9.6	11	7.4	2.8
Iron (Fe)	0.06	1.9	1.3	0.02
Calcium (Ca)	59	88	94	63
Magnesium (Mg)	3.1	3.3	9.6	6.5
Sodium (Na)	3.0	11	22	6.8
Potassium (k)		--	2.2	0.4
Bicarbonate (HCO_3)	168	266	266	218
Sulfate (SO_4)	20	2.4	34	8.3
Chloride (cl)	18	18	38	10
Fluoride (F)	0.3	0.1	0.1	0.2
Nitrate (NO_3)	.7	2.1	1.5	.3
Dissolved solids	195	294	370	212
Total hardness as $CaCO_3$	160	233	274	184

the raw water from the Miami Preston well field which is a short distance downgradient from the areas of thick organic soil in the Everglades. In contrast, the color at the Miami-Orr and Key West well fields is much lower because of the greater distance from the organic soils. The organic content in raw water can become a problem in the removal of color. Chlorine used in the treatment process has been shown to produce halogenated organics (principally trihalomethanes) some of which may be carcinogenic (Rook, 1975).

Treatment of public water varies from chlorination only to a comprehensive treatment which includes aeration, chlorination, coagulation, filtration, flocculation, pH control, softening, taste and odor control, recarbonation, and fluoridation.

GROUND-WATER WITHDAWALS

Municipal

In 1976 eighteen major utility companies operated 37 well fields and water-treatment plants in Dade County to supply about 345 million gallons on peak-demand days. In Broward County 49 major facilities (fig. 18) supplied nearly 155 million gallons per day. The average daily pumpage by the municipal system in Boca Raton was 17 million gallons in 1976. Figure 19 shows the areas in Dade and Broward Counties that are served by municipal or small public water-supply systems and those areas served by individual residential private wells (Planning Departments, Broward and Dade counties). Almost 84 percent of the developed area of Dade County is served by public water systems.

Irrigation

In 1975 a total of 62,350 acres were irrigated in Dade and Broward counties with an average for the year of 168 Mgal/d of canal and ground water. Wells produced 67 percent of the total. Water use is seasonal.

Most agricultural land in the area of the Biscayne aquifer is east of the water-conservation areas of the SFWMD but west of the urban coastal zone. Truck crops are the main produce. Irrigation and fertilization are required during the fall and winter. In recent years, new methods of planting under plastic sheets have reduced the requirements for irrigation water, fertilizer, and pesticides. Citrus, mango and avocado groves, are scattered along the coastal areas, to the west in south Dade County, and in inland parts of south Broward County. These groves require irrigation primarily during November through May. Most of the grove irrigation is by overhead sprinkling.

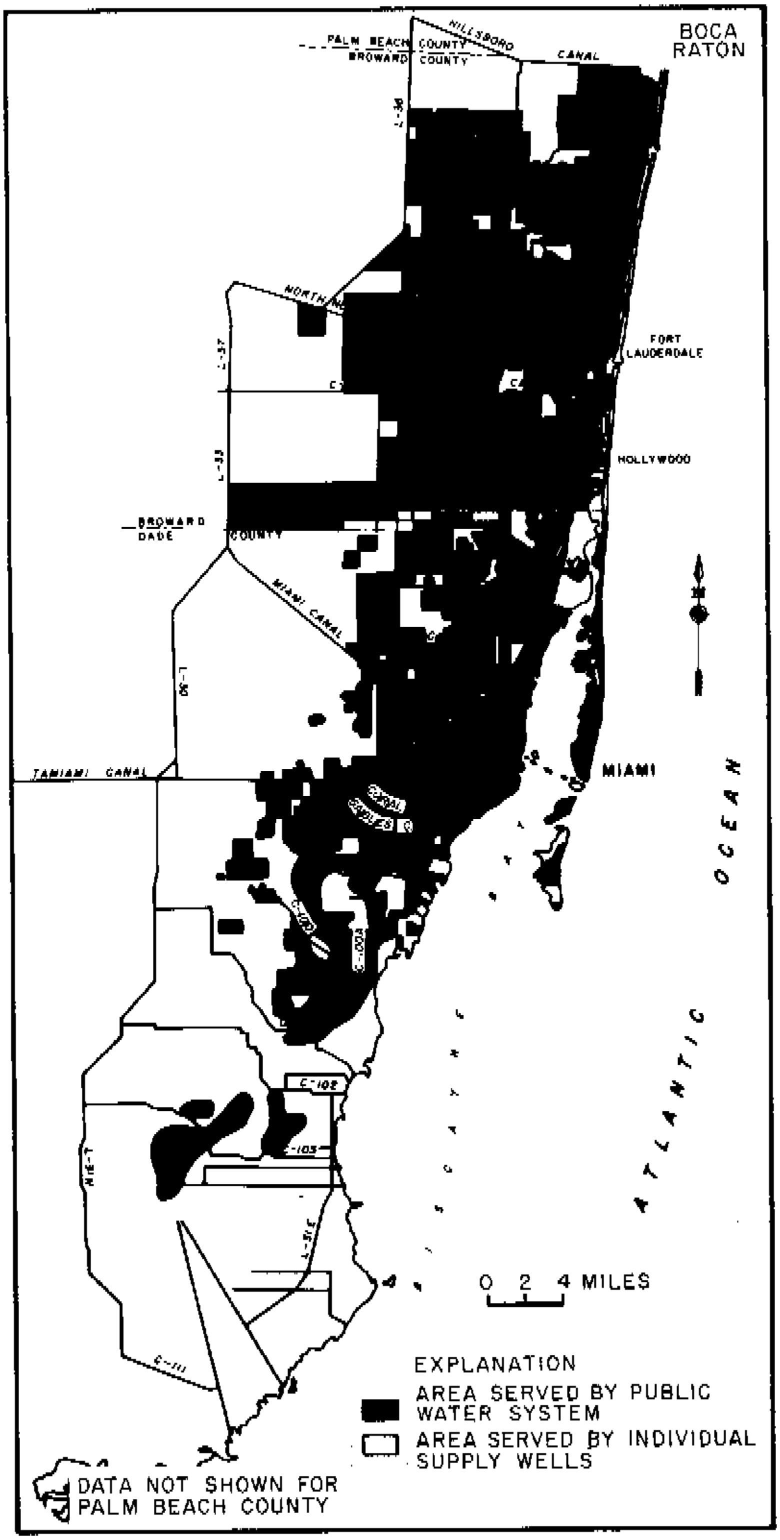


Figure 19.—Areas of public water-supply systems under franchise in Broward County and in service in Dade County, 1977 (Broward County Land Use Plan, 1977, p. 107; Metropolitan Dade County Master Plan, 1977, p. 52.

Effects of Pumping on Water Levels and Flow

Water levels are highest in the water-conservation areas and ground-water flow is generally toward the coast (figs. 7 and 8). Locally, flow direction may be influenced by canals and by pumping wells.

The direction of ground-water flow in the vicinity of the large municipal well fields is greatly influenced by continuous heavy withdrawals. The effects on water levels and ground-water flow in two of the large well fields are shown in figures 20 and 21. The water levels in the Hialeah-Miami Springs well field, in 1974, were lowered to 8 ft below sea level at the center of pumping (fig. 20), and ground-water flow was toward that center from the surrounding areas. The withdrawal rate in 1974 was 110 Mgal/d. Water from the adjacent Miami Canal and other local canals was leaking downward into the aquifer. An auxiliary well field is being established 0.5 mi west of the junction of the Miami Canal and the Florida East Coast Canal. It is designed to reduce the rate of withdrawal from wells in the south part of the municipal well field near the Miami International Airport, an area threatened by saltwater intrusion during the dry seasons.

The contours in fig. 21 show the effect on ground-water levels caused by withdrawal of 30 Mgal/d from the Fiveash well field of the city of Fort Lauderdale in May 1972. Water from Canals 13 and 14 was being diverted toward the center of pumping.

VULNERABILITY OF BISCAYNE AQUIFER TO CONTAMINATION

The Biscayne aquifer is vulnerable to contamination from several sources other than by saltwater intrusion: (1) Direct infiltration of runoff from buildings, yards, paved areas and agricultural areas; (2) infiltration from septic-tank drainfields, soakage pits or galleries dug into the upper part of the aquifer; (3) canals and rock pits cut into the upper part of the aquifer; (4) solid-waste disposal areas (landfills or dumps); (5) sewage treatment plant disposal ponds; (6) wells used for drainage of storm water; and (7) wells used for disposal of industrial waste. Disposal wells had been permitted by the local Health Department where ground water contains chloride concentrations more than 1,500 mg/L.

Contaminants that have entered the aquifer flow system travel toward the ocean, unless they are diverted by pumping wells, utilized by vegetation, are adsorbed by the limestone sand or marl that compose the aquifer, or chemically precipitate to form insoluble compounds. Travel time to the ocean may range from days to years, depending upon the location of the source and the nature of the contaminant, ground-water gradients, the hydraulic conductivity of the aquifer, and rainfall. Travel to the ocean is more rapid during the rainy season than during the dry season, and more rapid in areas near canals than in areas distant from canals. Movement of contaminants in the aquifer will have

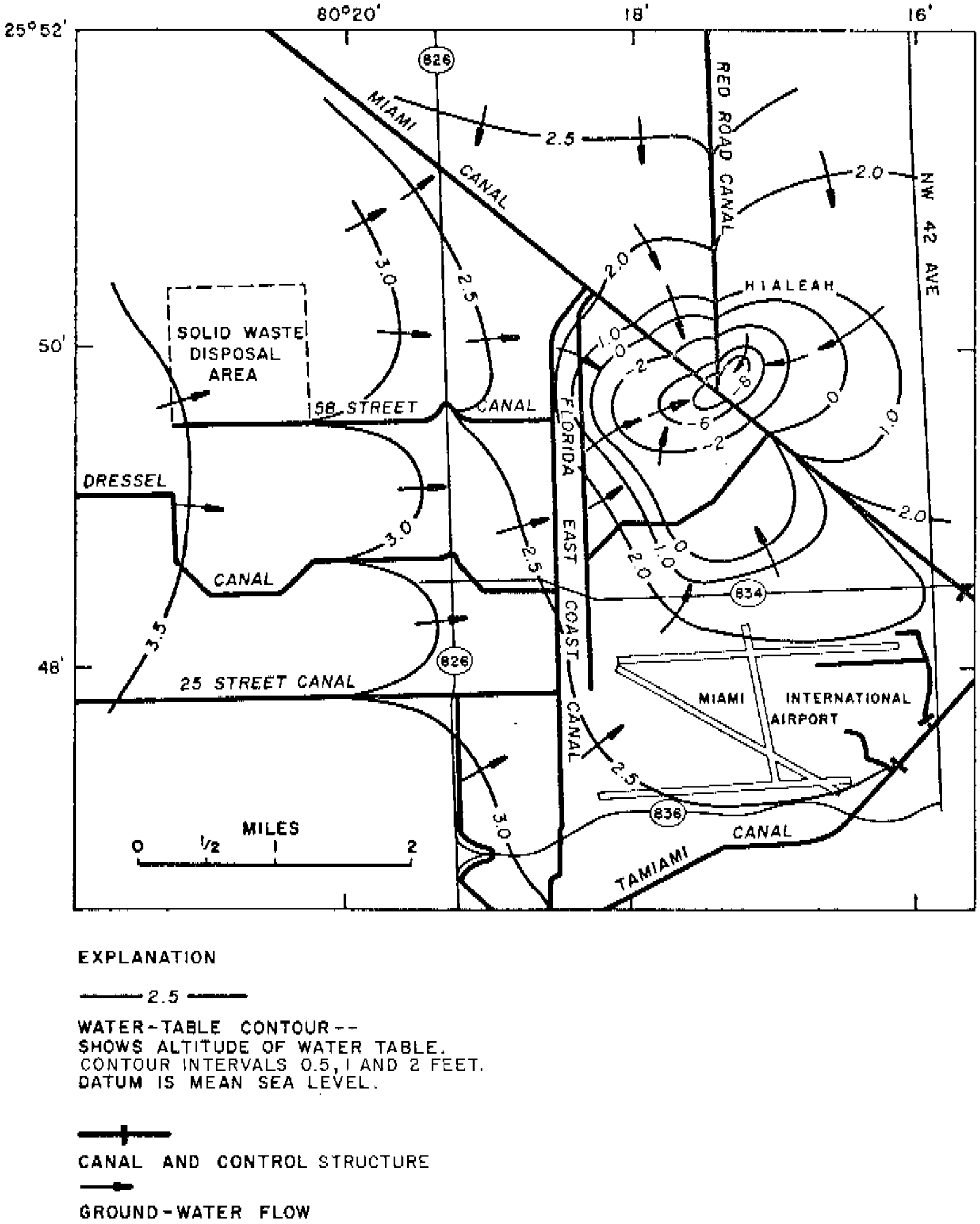
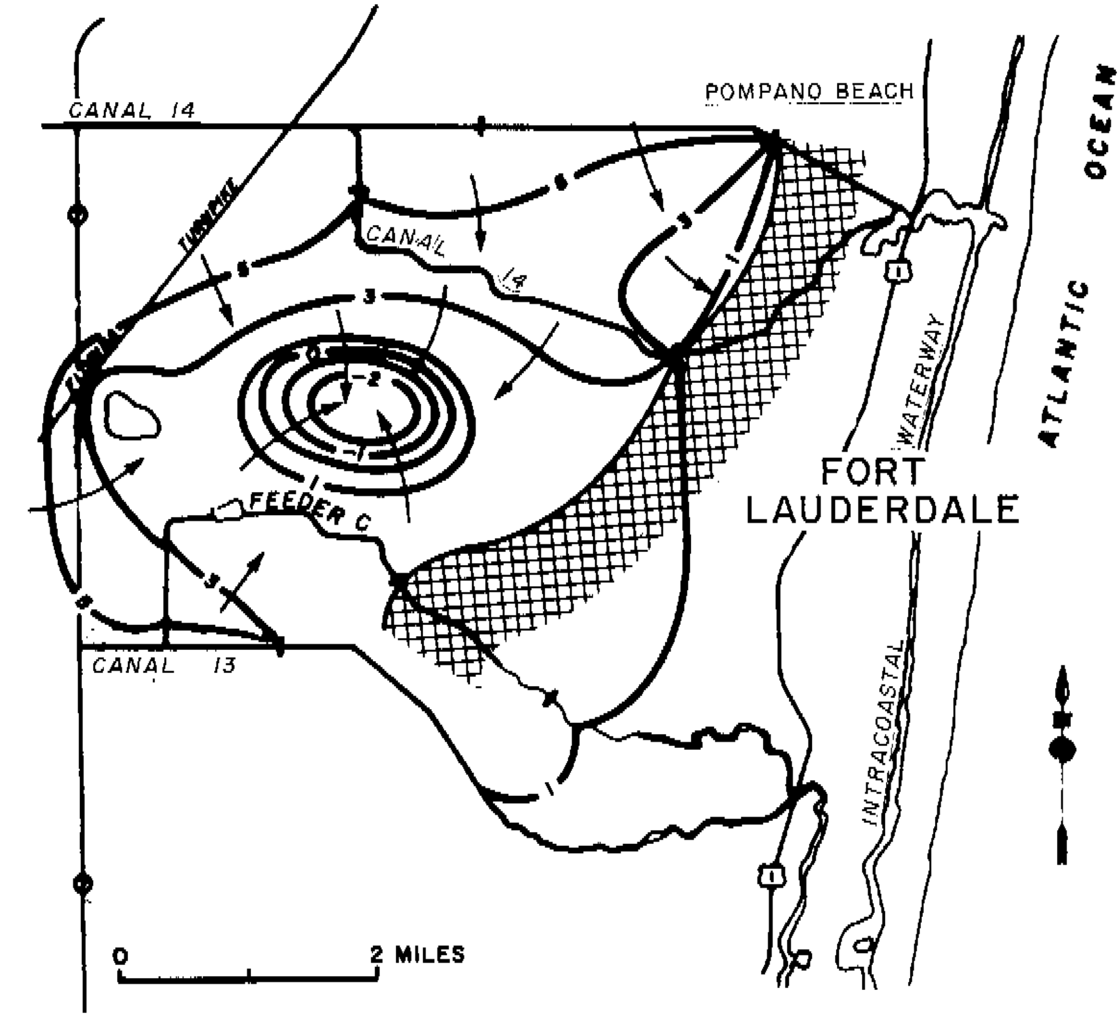


Figure 20.--Water levels and directions of ground-water flow in the Hialeah-Miami Springs well fields area, October 8, 1974 (from Hull and others, 1975).



EXPLANATION:

WATER-TABLE CONTOUR--
SHOWS ALTITUDE OF WATER TABLE. CONTOUR INTERVAL 1 AND 2 FEET. DATUM IS MEAN SEA LEVEL.

AREA AFFECTED BY SEA-WATER INTRUSION.

CANAL AND CONTROL STRUCTURE

GROUND-WATER FLOW

Figure 21.--Water levels and directions of ground-water flow in the Fort Lauderdale Fiveash well field area, May 1972 (from Klein and others, 1975, p. 106).

lateral and vertical components, influenced by the ground-water gradient, the density of the contaminant-containing liquid if it is different from that of the ambient ground water, and the relative horizontal and vertical hydraulic conductivity of the aquifer.

Waste-Water Disposal

In July 1976, 97 treatment plants having a total design capacity of 140 Mgal/d were treating 90 Mgal/d of waste water in Broward County (fig. 22). The majority of these were discharging secondary treated effluent at the coast or into major canals. Three of the largest plants discharge directly to ocean outfalls.

In 1977 only 47 percent of the developed area of Dade County was served with public sewers. Thirty-eight major waste-water treatment plants have a total capacity of 226 Mgal/d; the 3 largest of these comprise nearly 58 percent of the total treatment capacity of the county. In addition, 100 small plants have a total capacity of nearly 6.5 Mgal/d. Of the total effluent, 233 Mgal/d, about 115 Mgal/d is discharged directly to the ocean (of which 30 Mgal/d is untreated) and 7 Mgal/d is injected into saline aquifers through wells about 3,000 ft deep. The remaining 111 Mgal/d of secondary and tertiary treated effluent, is discharged to controlled and uncontrolled reaches of canals, soakage pits, or drainfields dug into the Biscayne aquifer.

The major waste-water treatment franchise areas in Broward County are shown in figure 23. Figure 23 also shows areas in Dade County served by sewers.

A significant part of the total sewage effluent generated in southeast Florida from residences and some industries is discharged into septic tanks. Pitt and others, (1975, p. 9), estimated that in 1970 nearly 175,000 septic tanks were discharging about 40 Mgal/d of domestic waste water to the aquifer in Dade County. In Broward County the Department of Pollution Control and the Area Planning Board estimated that about 80,000 septic tanks were discharging more than 28 Mgal/d into the aquifer in May 1972. Some of these septic tanks were eliminated as sewer systems were expanded while others were being installed in new residential areas.

One of the problems that continues to confront health and water-supply officials is that thousands of residences in southeast Florida still depend on individual shallow wells for water supplies in areas served by septic tanks. These individual supply wells usually range in depth from 20 to 50 ft in Dade County and more than 50 ft in Broward County. Pitt and others (1975) found measurable amounts of septic-tank effluent in the upper 20-30 ft of aquifer at five study sites in Dade County. Dispersion, dilution, and chemical processes presumably obscure direct evidence of septic-tank effluent at greater depths.

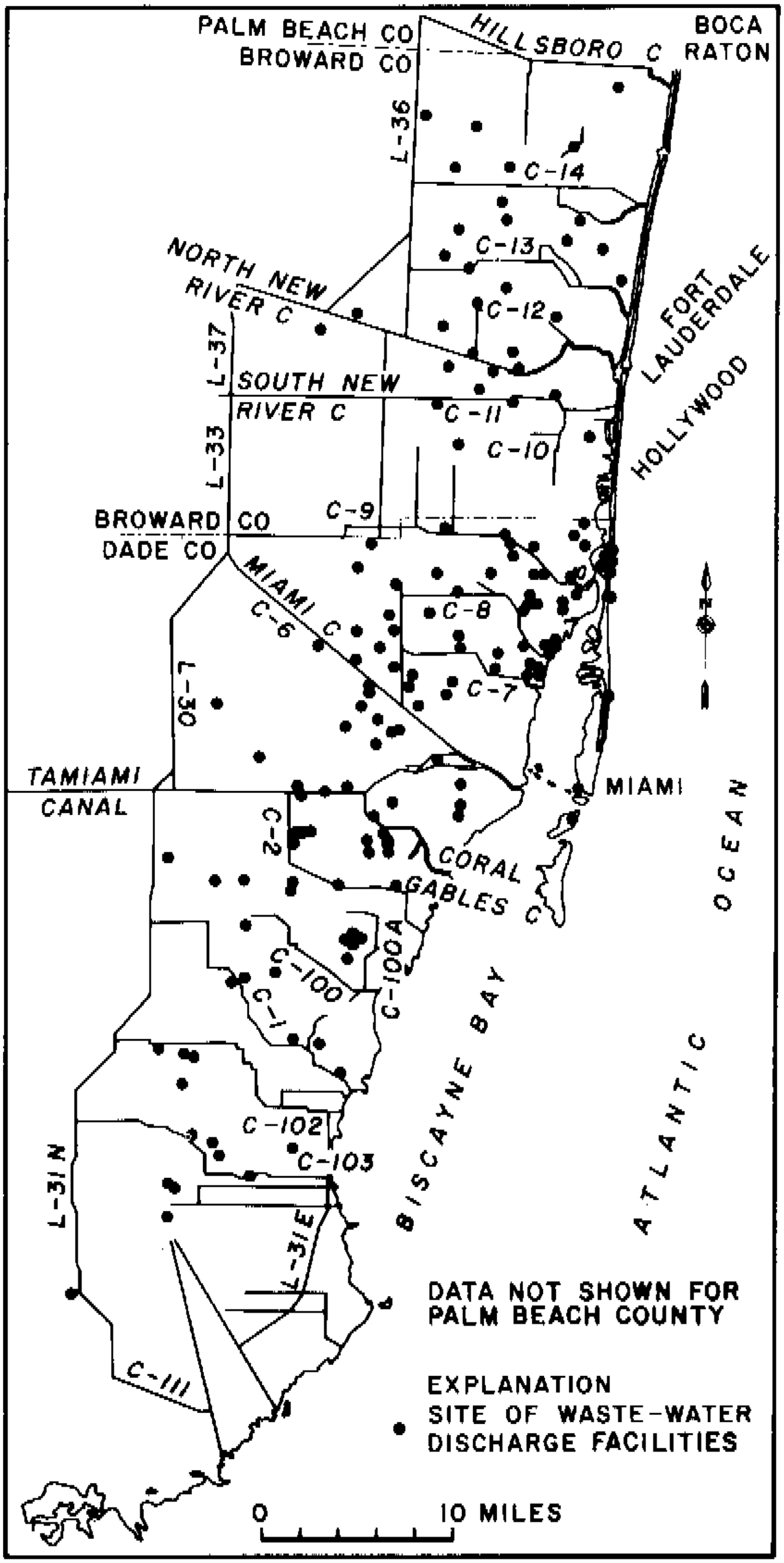


Figure 22.--Location of waste-water dischage facilities (Broward County Land Use Plan 1977, p. 115; Metropolitan Dade County Department of Environmental Resources Management facilities map, 1977).

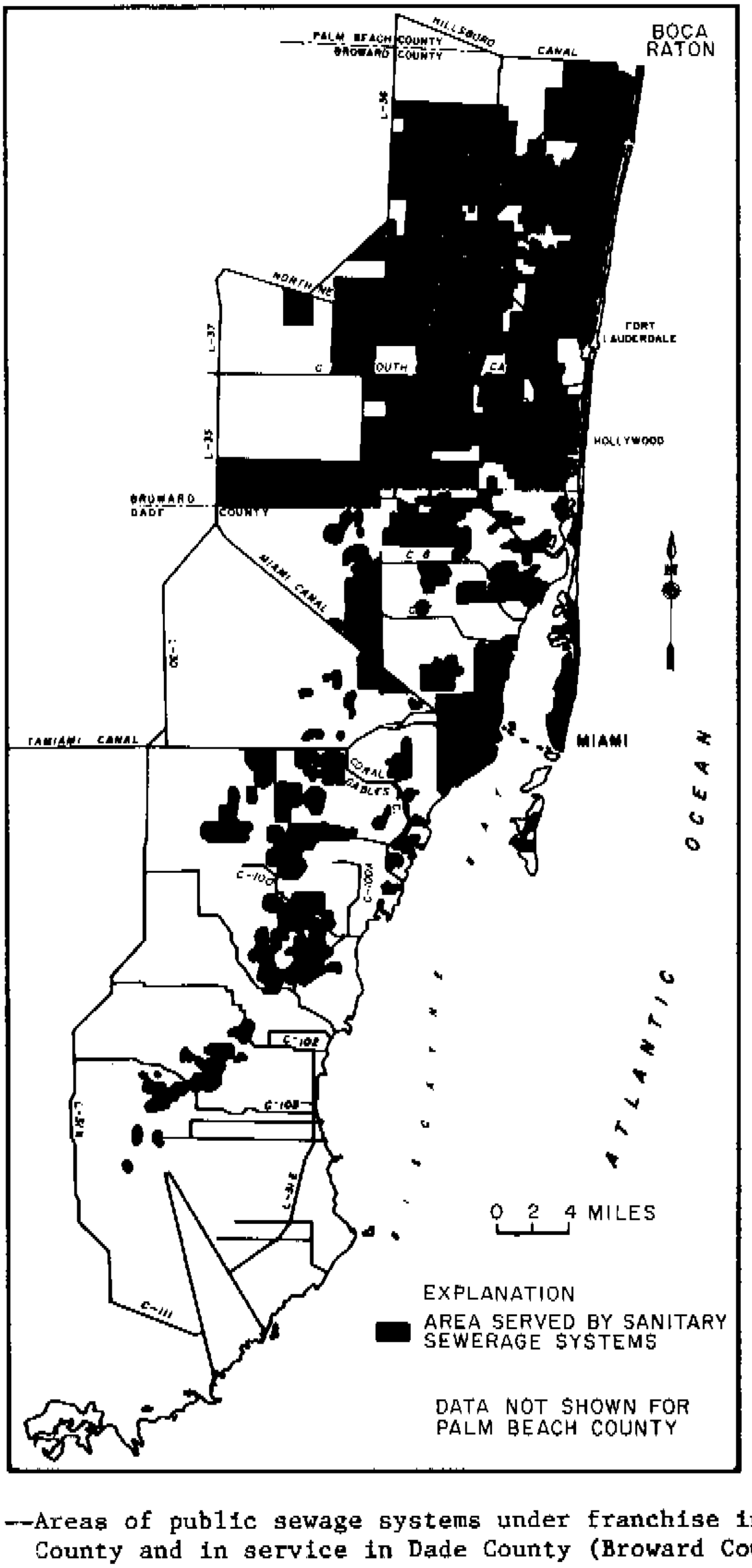


Figure 23.--Areas of public sewage systems under franchise in Broward County and in service in Dade County (Broward County Land Use Plan, 1977, p. 111; Metropolitan Dade County Master Plan, 1977, p. 54).

The conclusions by Pitt and others (1975) may not apply to the overall ground-water quality of densely populated urban parts of Dade and Broward Counties where the upper sections of the aquifer are primarily sand. Many of these older residential sections are still served by septic tanks. Because of lack of regular maintenance, septic tanks can become overloaded and the drainfields clog causing raw effluent and solids to be temporarily backed up. Pitt and others (1975, p. 20-21) inferred that along much of eastern Dade County where the water table is 8 ft or more below the drainfields, recognizable effluent from single family residential septic tanks may reach the water table only during times of heavy rainfall. Part of the effluent would be evaporated or utilized by lawn grass, shrubs and trees, and the remainder would filter into unsaturated sediments which may remove some of the constituents in the liquid. In low lying urban areas, effluent from residential septic tanks may reach the water table during dry seasons as well as wet seasons.

Wastewater is also disposed of through soakage pits or drainfields, by direct discharge to canals, and injection into deep wells. Soakage pits and drainfields are excavations in the upper part of the aquifer which are backfilled with gravel and sand to expedite vertical infiltration of effluents. These receive effluents from small treatment plants in interior areas where regional sanitary sewer systems are not available. The design capacity for these waste plants varies from 0.05 to 0.2 Mgal/d. Level of treatment is usually tertiary. The plants serve large condominiums and apartment complexes, shopping centers, small housing developments, hospitals, and large office buildings.

Some of the larger and older sewage treatment plants discharge effluent into canals. Treatment is usually secondary. Points of discharge for most of the plants are upstream of control structures. Because little or no flow occurs in those canals during the dry season, the canal water tends to become enriched by nutrients and at times algal blooms form. No studies have been made and no data have been obtained concerning extent of the lateral and vertical movement of nutrient-enriched water from the canals to the aquifer during dry periods when water levels in canals are higher than adjacent ground-water levels.

Injection of secondary treated sewage effluent into deep wells began in 1972 in a rapidly growing housing area southwest of Miami. The discharge is into cavernous dolomite and limestone at a depth of about 3,000 ft where the ground water has the salinity of sea water. The zone receiving the effluent is separated from the Biscayne aquifer by an 800-ft thick section of relatively impermeable fine sand and clay, and about 2,000 ft of permeable and poorly permeable limestone. Two deep well disposal systems are operating in Dade County and one in Broward County. A large capacity system is under construction (1978) in the near-coastal part of south Dade County for the Miami-Dade Water and Sewer Authority.

Solid-Waste Disposal

The disposal of solid wastes represents a potential source of contamination to the Biscayne aquifer because of the increasing volume of waste and trash generated and the need for disposal areas, the rapidity of aquifer recharge, and the shallow depth of the water table. The distribution of solid-waste disposal sites in the two-county area is shown in figure 24. The distribution includes closed, transfer, and active disposal sites. Even though a site is closed, it may contribute leachates because of continued decomposition of waste materials.

Investigations of ground-water quality have been made in the vicinity of solid-waste disposal facilities 5 mi northwest of Pompano Beach, and near the western city limits of Hialeah. The facilities have been in operation more than 15 years. The site near Pompano Beach is underlain by unconsolidated medium to fine sand which permits vertical movement of leachate. Water from 20-ft deep wells less than 100 ft downgradient of that facility contained average dissolved solids concentrations ranging from 1,587 mg/L to 1,677 mg/L. Water from wells 90-ft deep at the same site contained 475 mg/L, about the same concentration as water from shallow and deep wells upgradient from the disposal area. Shallow ground water in the upgradient, uncontaminated area contained 413 mg/L dissolved solids (Pitt, 1975, Table 2).

The solid-waste disposal facility near Hialeah is 3 mi upgradient (west) from the largest municipal well field in southeast Florida (fig. 20). The direction of ground-water flow in the vicinity of the well field suggests that leachate from the disposal area is migrating toward the pumping wells. The calculated average rate of ground-water movement was 2.9 ft/d (feet per day) (Mattraw, and others, 1978). The distribution of specific conductance of ground water along a west-east profile beneath the disposal area in October 1974 is shown in fig. 25 (Mattraw and others, 1978, fig. 20). Conductance values are greatest immediately beneath the disposal area, and decrease with depth. The pattern of the distribution shows the downgradient migration of the leachate, influenced partly by the heavy well-field pumpage to the east. Mattraw and others (1978) indicate that the occurrence of leachate at distances greater than 0.5 mi from the source is difficult to determine because dispersion and recharge dilute contaminant concentrations in the plume to concentrations that are virtually equivalent to ambient concentrations.

In general, the extent, shape, and concentration of the leachate plumes that form depend upon the following: (1) The vertical and horizontal permeability of the aquifer; (2) the types and volumes of waste; (3) the duration of the waste-disposal operation; (4) amount of infiltrated rainfall; (5) the adsorbant properties of the geologic materials that compose the aquifer, and (6) the hydraulic gradient.

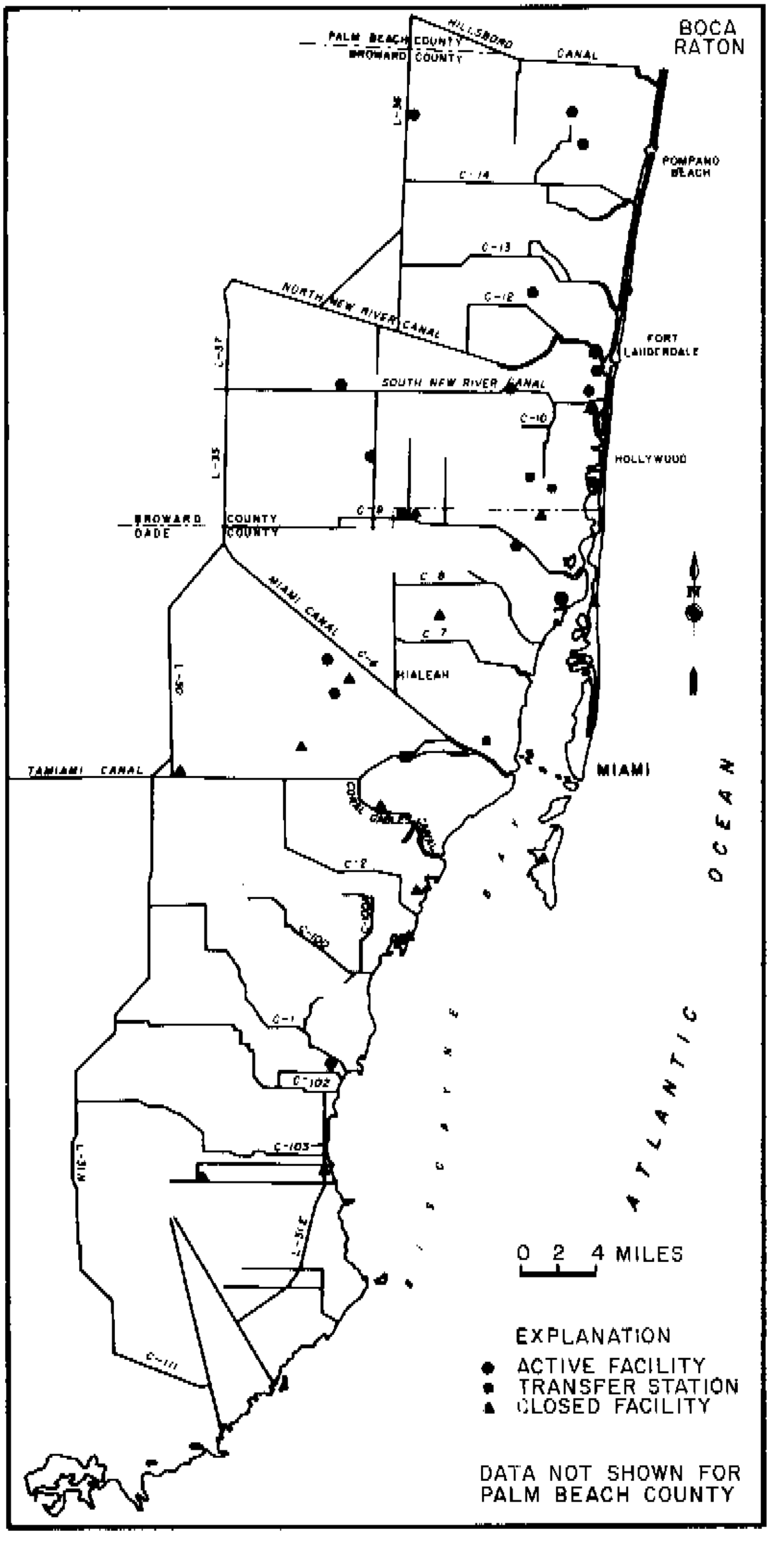


Figure 24.—Locations of solid-waste facilities, 1977, (Broward County Land Use Plan, 1977, p. 128; Metropolitan Dade County Environmental Resources Management facilities map, 1977).

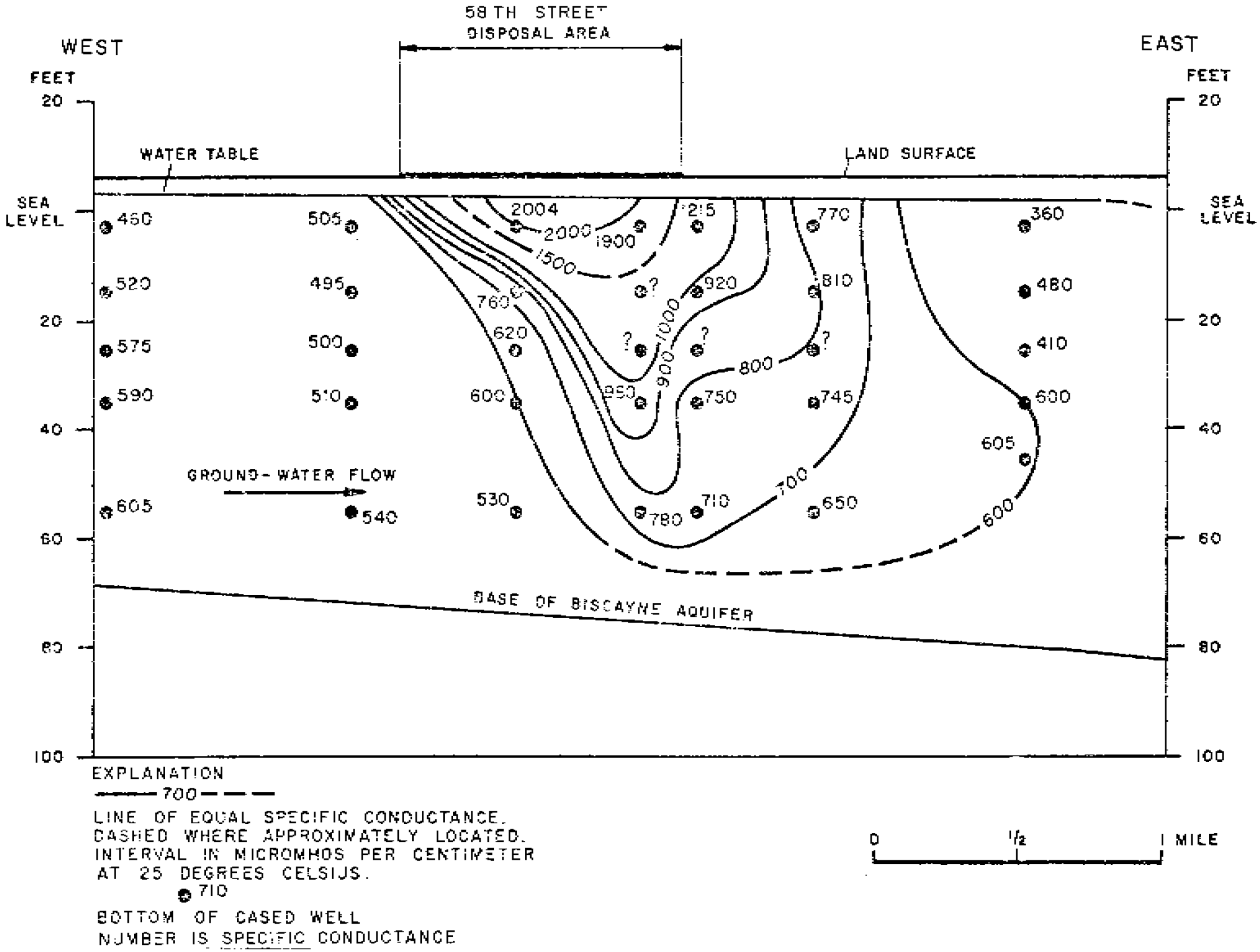


Figure 25.--Lines of equal specific conductance in vicinity of the Northwest 58th Street solid-waste disposal area, October 1974 (after Mattraw and others, 1978).

Urban and Agricultural Runoff

Runoff from urban and agricultural areas has caused deterioration of the quality of canal water and to a lesser extent, ground water. Runoff enters the aquifer by surface infiltration, infiltration from canals, soakage pits, infiltration galleries or drainfields, french drains, and by drainage wells. Runoff enters canals and lakes by overland flow, through outfalls of storm-sewer systems, and by ground-water discharge.

Urban runoff contains a large variety of substances and chemicals including residues from automobile traffic on hundreds of miles of heavily traveled roads, household refuse, fertilizers and insecticides, and animal waste. A summary of water-quality data from sites on selected canals in urban parts of Dade County for 1976 is given in Table 3. These data were collected monthly by the Dade County Department of Environmental Resources Management. The sites on the Coral Gables waterway and Wagner Creek (near downtown Miami) are in uncontrolled (tidal) reaches of canals; the remaining sites are along controlled reaches of canals.

The quality of the storm runoff from a low density (4 single-family residences per acre) residential area in Broward County is compared with a comparable acreage high density (multi-family apartments) residential area in Dade County in Table 4. The nutrient content in the runoff from the Broward County area was generally higher than in Dade County probably because of the large percentage of lawn area contrasted with the large paved vehicle-parking area in the Dade County site. Much of the nutrient content comes from fertilized lawns and shrubs in low density residential areas.

Pollution from urban areas is greatest near the coast where housing density is greatest and paved areas are maximum. Storm runoff in the coastal urban areas is generally to storm sewer systems connected to treatment plants or to tidal reaches of the nearest canals and then to tidal water. In near coastal areas not served by sewers, storm water infiltrates the aquifer directly and carries contaminants downward. In these areas, the residence time of contaminants that reach the saltwater zone of the aquifer is short because of the proximity to points of discharge to tidal waters.

In less dense populated areas farther inland, storm-water runoff from residential areas, small shopping centers, and roadways infiltrates directly into the aquifer. The thin soil, yard grasses and the shallow sections of limestone and sand above the water table tend to take up nutrients or filter or adsorb part of the pollutants before they reach the water table. The pollution loads are greatest at the early part of the rainy season when the "first flush" of the adsorbed or filtered constituents occurs. Subsequent rainfalls produce decreasing loads. Runoff from large shopping centers with multi-acre parking facilities is usually piped to a large sump to remove solids and other debris and then to a soakage pit or drainfield where it infiltrates the aquifer. If the area is near a controlled canal, the runoff may be discharged there.

Table 3.— Water quality in selected canals, 1976

[Data from files of Department of Environmental Resources Management, Dade County]

Sample Station Location	Dissolved Oxygen (DO)			Biochemical Oxygen Demand (BOD)			Phos Phosphate (PO4)			Coliform Bacteria			pH	
	1976 DATA													
	Mg/L			Mg/L			Mg/L			per 100 mL (MPN)				
	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX	AVG	MIN	MAX
Miami Canal	0.9	6.6	3.0	0.4	2.8	1.6	0.09	0.40	0.28	45	17,000 Median 1,300	3,210	7.1	7.6
Red Road Canal	1.5	5.4	3.3	.4	2.8	1.8	.09	.45	.27	18	240,000 Median 1,245	37,266	7.2	7.8
Red Road Canal	1.5	6.3	3.3	.8	3.0	1.8	.09	.24	.18	490	35,000 Median 3,300	7,582	7.3	7.7
Miami Canal	1.4	6.8	3.3	.6	3.3	2.8	.07	.11	.09	130	11,000 Median 1,045	2,872	7.1	7.6
Coral Gables Waterway	2.0	6.6	4.7	.8	3.4	2.1	.02	.18	.11	45	7,900 Median 640	1,539	7.2	8.2
C-100 A Canal	2.5	15.8	8.8	1.0	3.6	2.2	.09	.54	.31	78	92,000 Median 2,750	10,992	7.1	7.6
Wagner Creek (tributary of Miami River)	0.4	2.6	1.6	0.2	9.2	2.7	.09	.34	.22	2,300	240,000 Median 92,000	111,618	7.1	7.6
Snapper Creek	1.5	7.0	3.6	1.8	15.2	3.9	.25	.42	.39	330	24,000 Median 2,300	3,900	7.0	8.0
C-100 Canal	3.2	8.6	6.3	0.4	2.8	1.8	.09	.61	.25	230	3,300 Median 1,300	1,578	7.1	7.9
Coral Gables Waterway	4.5	9.3	7.0	1.2	17.2	3.9	.02	.50	.23	330	24,000 Median 3,300	7,919	7.1	8.7

Table 4.— Quality of runoff in high and low density residential areas.

	Broward County Low Density Residential				Dade County High Density Residential			
	No.*	Mean	Minimum	Maximum	No.*	Mean	Minimum	Maximum
Organic Nitrate-N (mg/L)	344	1.23	0.18	9.4	27	0.913	0.37	2.6
Ammonia-N (mg/L)	342	0.343	.01	2.6	27	.031	.01	0.07
Nitrate-N (mg/L)	344	.484	.0	2.1	27	.067	.0	.15
Total Phosphorus as P (mg/L)	344	.317	.06	2.4	27	.204	.12	.50
Total Orthophosphate as P (mg/L)	345	.218	.03	1.8	27	.094	.03	.23
Copper (ug/L)	-	8.3	0	41	51	9.34	0	45
Iron (ug/L)	275	317	0	5,300	51	476	100	2,600
Lead (ug/L)	-	167	30	1,100	51	213	20	1,100
Zinc (ug/L)	-	86.7	10	560	51	168	20	790

*Number of samples

Pollutant concentrations increase only temporarily in the canal water during the rainy season because the control structures in canals are opened repeatedly to discharge surplus water to the coast and pollutants are flushed to the ocean. A large part of that surplus comes from shallow ground water in areas adjacent to the canals. Flushing of shallow ground water occurs annually during the rainy season; the amount of flushing is dependent on the frequency and amount of rainfall and the locations of pollutants with respect to drainage canals. Flushing in shallow parts of the aquifer is less effective in areas distant from canals than in areas adjacent to canals.

Contribution of pollutants to the aquifer and to canals in the urban areas is minimal during the dry seasons. However, moderate-to-heavy, infrequent storms and attendant runoff can result in build-up of nutrients and other pollutants in shallow parts of the aquifer and in canals. These infrequent contributions tend to build up because control structures are closed. The only other contributions to canals are from inflows of ground water in the upgradient areas which contain nutrients from the use of fertilizers in residential areas and from septic tank effluent. In the downgradient reaches of canals where the canal water is higher than the ground water level, some filtration and adsorption of the nutrient-rich canal water takes place as the canal water seeps into the aquifer.

A part of the nutrient enrichment of ground water and canal water is from agricultural areas of interior Broward County and south Dade County. Analyses of ground-water showed no pesticide content but an occasional low concentration of the herbicide, silvex. The canal water in Broward and Dade Counties frequently contains detectable but low concentrations of silvex and 2-4D, and occasionally dieldrin, diazinon, lindane, and polychlorinated biphenyls. In contrast, canal-bottom sediments, contain a greater variety of herbicides and insecticides at much greater concentrations (Mattraw, 1975).

Pitt and others, (1975, p. 51) suggested that uniformly high nitrate concentrations in water from certain observation wells of different depths in south Dade County are probably related to the extensive and long-term agricultural activity in south Dade County. Citrus, avocados, and mangos have been grown for many years in south Dade County. Fertilizer and pesticides are used regularly and irrigation is from thousands of shallow wells throughout the dry seasons. Also, in south and inland Dade County and part of north Broward County, truck crops grown during October - February require frequent irrigation and regular fertilization. Irrigation in both counties is primarily by overhead sprinkler. The root systems are moistened, but little of the applied water leaks to the water table because of high evapotranspiration. Salts from fertilizers tend to accumulate in the soil zone and are washed downward into the aquifer during the first heavy rains of the rainy season.

Infiltration of water is rapid in south Dade County because solution-riddled limestone is at the surface. Infiltration is less rapid in north Dade County and most of Broward County where fine sand and other unconsolidated sediments underlie the surface to a depth of several feet. These sediments tend to filter out and concentrate pollutants at shallow depths within the saturated zone of the aquifer.

A method of storm-water disposal, used more in Dade County than in Broward County, is through wells cased to saltwater zones in coastal parts of the Biscayne aquifer. An undetermined number of these wells along the coastal zone are receiving runoff from parking lots, shopping centers, and other paved areas. These wells are usually cased to deep parts of the aquifer which contain water whose chloride concentration is greater than 1,500 mg/L. The storm water is untreated. No information is available concerning the specific paths of storm-water in the immediate area in the saltwater zone of the Biscayne aquifer.

FUTURE PROBLEMS OF POTABLE SUPPLIES

Future problems affecting the potable water supplies of the Biscayne aquifer are related to continued growth of population and industry. Continued growth will result in increased demands for potable water and increased generation of waste water and solid waste. Until such time that costs of desalination become competitive with costs of obtaining freshwater from the aquifer, agencies will continue to depend upon the Biscayne aquifer as the prime source. The current and future policies of the public utilities generally involve unifying or incorporating the many small individual water-supply and waste-water systems into larger regional systems for more efficient operation and more uniform treatment.

Water Availability and Quality

A prime consideration in providing potable water supplies for future demands will be saltwater intrusion into the aquifer. The existing major municipal well fields will continue operation, although some may be at reduced pumping rates because of the potential for saltwater intrusion. Additional supplies for satisfying future demands will be from well fields inland from those operating in 1978, greater distances from the threat of saltwater intrusion.

Future water needs will rely heavily upon the practices, operations, and water-use plans of the SFWMD. One recommendation of the District is to locate new supply wells further from major canals. This will maximize withdrawal of ground-water from aquifer storage, minimize reliance on diversion from canals and tend to insure that adequate quantities flow through the canals to the coast to retard saltwater intrusion.

However, pumping will eventually divert canal water into the aquifer and to the pumping wells. The quality of the ground water withdrawn will then resemble the chemical characteristics of the canal water. As pumping rates increase, greater reliance will be on inflow from the canals and the water-conservation areas. The main canals that transect Broward and north Dade Counties obtain water from the water conservation areas that is high in organic content. It would be expected that organic-rich water would be diverted toward the wells, altering the chemical quality of the ground water. The sand and limestone of the aquifer would filter some of the organic compounds.

Another problem related to reliance on the water conservation areas and Lake Okeechobee for replenishment during dry seasons is the gradual degradation of the replenishing waters. The quality of the interior waters may become degraded because of backpumping of surplus water from the agricultural areas south of Lake Okeechobee and because of the inferior shallow ground water, southeast of Lake Okeechobee as shown by Parker and others, (1955, fig. 221). The surplus water backpumped into Lake Okeechobee or pumped into the conservation areas contains nutrients and other chemicals from farming activities. Joyner (1971, p. 86) has indicated that the early eutrophic condition of Lake Okeechobee was due in part to backpumping. Because the water in the lake and the conservation areas is channeled through canals to the southeast to replenish the Biscayne aquifer during dry seasons, the potential for degrading ground water is apparent.

One of the water-management schemes proposed by the SFWMD is to backpump part of the surplus storm water in the urban and suburban areas of southeast Florida to the water conservation areas, thus, reducing the discharge of freshwater to the ocean. The total daily flow to the ocean of the major canals of the lower east coast ranges from 1,000 ft^3/s (650 Mgal/d) during a dry year to more than 6,800 ft^3/s (4,400 Mgal/d) during a wet year (McPherson and others, 1976, p. 55). The average flow is 2,550 ft^3/s (1,650 Mgal/d) during an average rainfall year. These discharges are presently (1978) considered necessary by the District to prevent flooding in developed areas. The water to be backpumped probably will contain some toxic substances and nutrients from the urban and agricultural areas, which in sufficient quantities, could further degrade the water stored in the conservation areas. Some of the nutrients would be utilized by the vegetation in the conservation areas and some toxic substances possibly would be adsorbed by the organic soils.

During the past decade urbanization has been spreading inland toward the water conservation areas, into undeveloped land, and land already devoted to farming. Future growth probably will maintain that pattern because the interior land is less costly than land near the coast. The inland areas are of low elevation and are subject to periodic flooding. As indicated, the interior parts and the water-conservation areas are where ground-water flow originates during the dry seasons. If those areas were to urbanize, such contaminants as might be associated with urbanization could degrade the ground water.

OTHER DRINKING WATER SOURCES

A major source of freshwater in southeast Florida is Lake Okeechobee (fig. 3). Although the Everglades-Lake Okeechobee basin and the Biscayne aquifer form a single hydrologic system within the SFWMD, Lake Okeechobee can be considered a separate source because it does not directly overlie or adjoin the Biscayne aquifer. It is the prime surface reservoir in the hydrologic system. It is supplemented by the three water-conservation areas to the south. In addition to rainfall, the lake is fed primarily from the north by the Kissimmee River and by pumpage of excess water from the northern part of the Everglades farming areas.

Water from Lake Okeechobee is used for irrigation in the agricultural area south of the lake and citrus groves east and northeast of the lake. The lake is the source of water for most of the bordering towns and farming areas and a few public supplies west and southwest of the lake. Use of water from the lake would be limited by lake-level regulations to provide navigation.

The Florida Keys Aqueduct Authority is producing small quantities of potable water from desalination of sea water and ground water from the Floridan aquifer in the Florida Keys facilities. In southeast Florida, the Floridan aquifer at depths from 800 ft to 1,500 ft yields by artesian flow, brackish water whose chloride concentration is from less than 1,500 mg/L to about 2,500 mg/L. The brackish to saline water in the Floridan aquifer represents a very large virtually untapped source of water for uses other than those that require freshwater.

One of the methods of conserving water under consideration by the SFWMD is to store surplus storm water by injection into the Floridan aquifer. Results of tests in the Miami area by F. W. Meyer, U.S. Geological Survey (personal commun., 1977) showed that several weeks after injecting freshwater into the Floridan aquifer at a rate of 1 Mgal/d, more than 50 percent of the injected water was recovered. Further investigation testing is needed to determine the feasibility of large-scale injection and recovery of storm water. Studies are also needed to evaluate the renovation and possible subsequent recovery of treated sewage effluent injected into the Floridan aquifer.

SUMMARY

The Biscayne aquifer of southeast Florida is the prime source of drinking water for all municipal water systems south of Palm Beach County. It is a wedge-shaped body of highly permeable limestone and sand which extends from the land surface to a depth of more than 200 ft along the coast and thins out 40 mi west under the Everglades. The aquifer is unconfined and is recharged primarily by rainfall. Discharge from the aquifer is by a system of canals for flood prevention, by pumping wells primarily for public supplies and irrigation, by evapotranspiration, and by subsurface outflow along the coast. The Biscayne aquifer is the prime unit of the hydrologic system managed by the SFWMD.

Ground-water quality of the Biscayne aquifer is affected by: (1) Proximity of areas to the thick organic soils of the Everglades which impart high color; (2) nature of the composition of the aquifer; (3) local land-use and introduction of pollutants; (4) frequency, intensity, and composition of the rainfall; (5) biological processes at land surface and within the aquifer; (6) chemical reactions among dissolved constituents and between the water and rock; and (7) saltwater intrusion.

Because the aquifer is highly permeable and permits rapid infiltration of rainfall, it is vulnerable to contamination by substances carried downward by recharge water. Furthermore, it is subject to contamination from controlled canals because of the good hydraulic connection between canals and the aquifer. Six major sources of contamination are: (1) Infiltration of runoff from buildings, yards, paved areas, and agricultural areas; (2) infiltration of septic-tank effluent; (3) sewage plant soakage ponds; (4) drainage wells; (5)canals and rock pits; and (6) solid-waste sites.

Water-quality data obtained from a few investigations in septic-tank areas and solid-waste areas have found the most objectionable substances from these sources in the upper 20 to 30 ft of the aquifer. Objectionable substances could be diverted downward in areas of heavy pumping. Dispersion and adsorption tend to reduce the concentrations of polluting substances and the seasonal heavy rainfall and canal discharge contribute toward diluting and flushing the upper zones of the aquifer. Expansion of urbanization into remote areas of high water levels, and the attendant urban runoff could contribute such contaminants as associated with urbanization in presently undeveloped lands, and thereby, affect water quality in downgradient sections of the aquifer.

The peak daily withdrawal from the aquifer for municipal purposes in 1976 was 500 Mgal/d. Another 165 Mgal/d was pumped for irrigation of crops. Most municipal well fields are located within residential or industrial areas. The quality of the raw water at each field reflects the many years of pumping, infiltration of urban runoff, contributions from thousands of septic tanks, agricultural activities, and seasonal rainfall infiltration and canal drainage.

Other sources of freshwater in southeast Florida are Lake Okeechobee and its tributaries. However, water from the lake is already heavily utilized for irrigation and public-water supplies. Potential supplemental sources of freshwater are desalination of water from the Floridan artesian aquifer, and subsurface storage of excess storm water.

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